2
am 17

NASA CR-112329

EARTH ORBITAL EXPERIMENT PROGRAM
AND
REQUIREMENTS STUDY

VOLUME 5

COMMUNICATIONS AND NAVIGATION

(APPENDICES A, B, C)

Prepared under Contract No. NAS1-9464 by
McDONNELL DOUGLAS CORPORATION
5301 Bolsa Avenue
Huntington Beach, California 92647

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

The information presented in this report summarizes three major steps toward production of a reference manual for planners of manned earth-orbital research activity. The reference manual will serve as one of the principal tools of a systems approach to experiment and mission planning based on an integrated consideration of candidate research programs and their attendant vehicle, mission, and technology development requirements.

The first major step toward preparation of the manual was the development of long-range goals and objectives suitable for NASA's activities during the 1970-1980 time period. This work was completed by NASA Headquarters with active center support and was published in September 1969 as a portion of a report for the President's Space Task Group entitled, "America's Next Decade in Space."

The second major step was a contractual study effort undertaken in September 1969 by McDonnell Douglas Astronautics Company-West with the TRW Systems Group, the IBM Federal Systems Division, and the RPC Corporation. The purpose of the study was to structure the NASA-developed goals and objectives into an orderly, system-oriented set of implementation requirements. The contractor examined, in depth, the orbital experiment program required to achieve the scientific, technological, and application objectives, and determined in a general way the capabilities required in future manned orbital programs to accommodate the defined experiments. Thus, the basic task of the contractor was to aid NASA in studying the useful and proper roles of manned and automated spacecraft by examining the implementation alternatives for NASA experiments.

The third major step presented in this document is the result of an integrated consideration of NASA's long-range goals and objectives, the system and mission requirements, and the alternative implementation plans. It will serve as a source of detailed information and methodology for use by NASA planners in development and justification of future programs.

Management

Technical direction (fig. 1) of the contracted study effort is the responsibility of the Advanced Aerospace Studies Branch (AASB) of the Space Systems Division (SSD) at the Langley Research Center (LRC). Technical guidance is provided by the Earth Orbital Experiment Program Steering Group which reports through the Planning Steering Group (PSG) to the Associate Administrator. Technical coordination is also maintained with appropriate personnel at ARC, GSFC, MSC, and MSFC.

The membership of the Steering Group (fig. 2) comprises representatives of the working groups of the PSG under the chairmanship of Dr. R. G. Wilson, Director, Advanced Programs, OSSA. The NASA Study Management Team is headed by Mr. W. R. Hook of the AASB. Technical support is supplied by elements of the Langley Research Center as required.

The contractor's Study Team is headed by Dr. H. L. Wolbers, MDAC, and the Senior Management Review Council is chaired by Mr. C. J. Dorrenbacher, Vice President, Advanced Systems and Technology, MDAC.

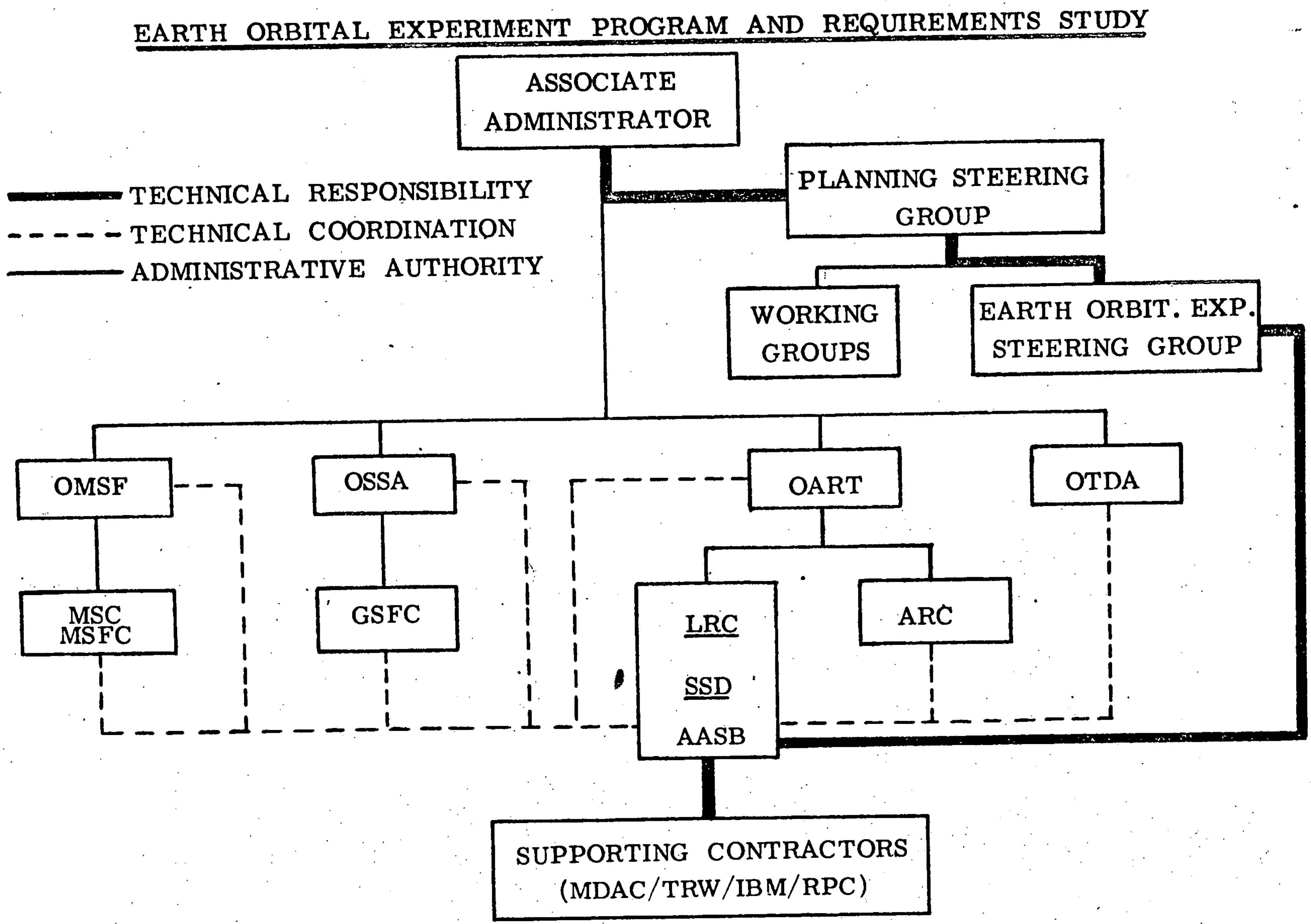


Figure 1. - Management Plan.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

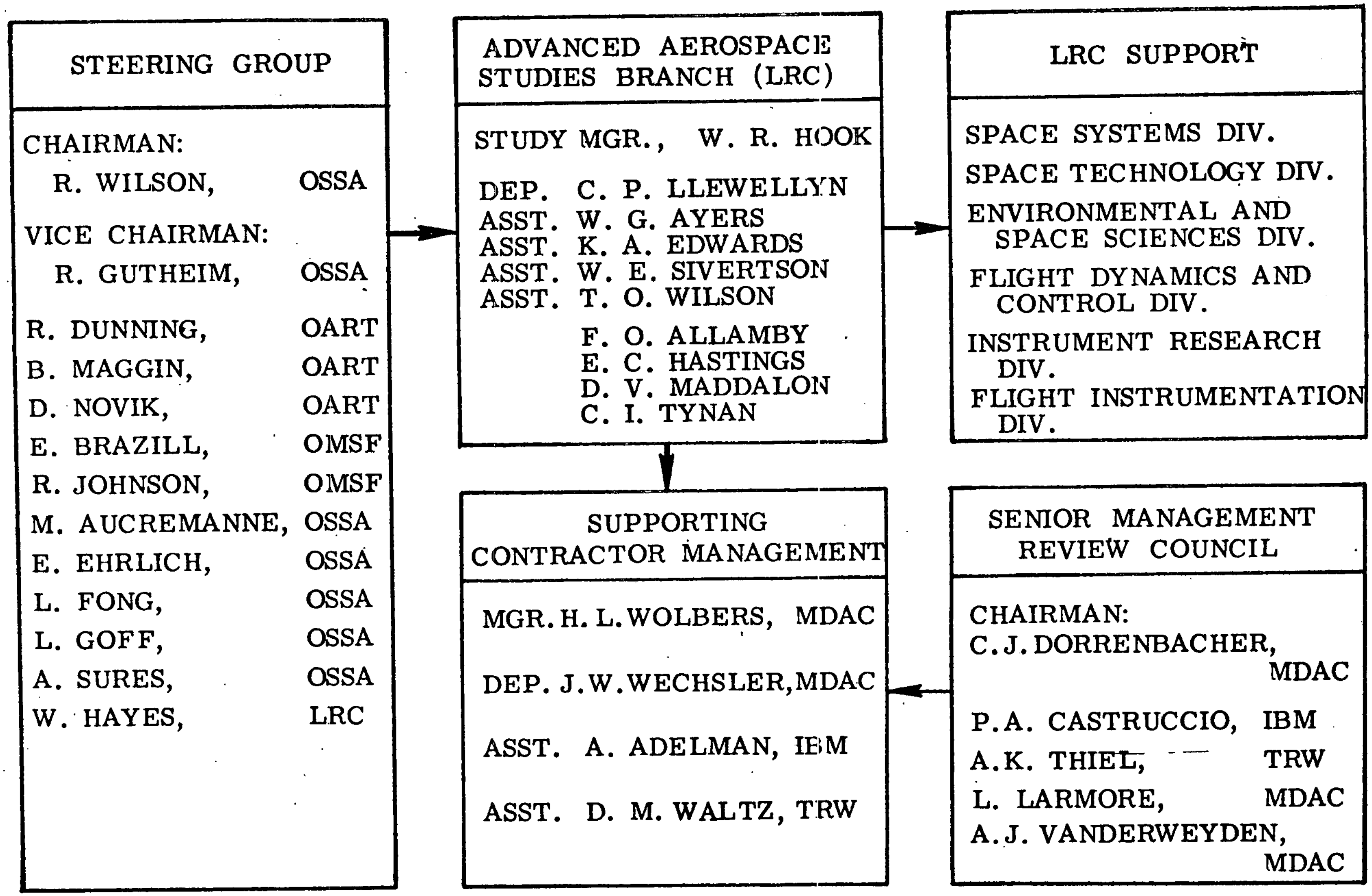


Figure 2. - Study Team.

APPENDIX A

ORGANIZED OVERVIEW

CHARTS

COMMUNICATIONS AND NAVIGATION

I

INTRODUCTION
APPENDIX A

The organized overview method of analysis is described in Section 2, in general terms as well as specific detail for each of the six study disciplines. The organized overview charts derived in each of these disciplines are presented in this Appendix, as follows:

Manned Spaceflight Capability	Charts 1-1 through 1-90
Space Biology	Charts 2-1 through 2-14
Space Astronomy	Charts 3-1 through 3-42
Space Physics	Charts 4-1 through 4-17
Communications and Navigation	Charts 5-1 through 5-9
Earth Observations	Charts 6-1 through 6-29

Critical issues referred to at the lower levels of these charts are found in Tables 1 through 6 in Appendix B.

I-a

Chart 5-1. Organized Overview for Communications and Navigation

5.0 COMMUNICATIONS AND NAVIGATION

Objective: To exploit space technology to fulfill the need for transfer of information and for control and coordination of vehicles over distances that are large compared with localized spheres of human activity.

5.1 COMMUNICATIONS

How may natural and technological resources be augmented and utilized to best fulfill mankind's growing needs for information exchange?

5.1.1 APPLICATIONS

What developmental systems can best meet unfulfilled needs for communications and/or navigation services, best stimulate development of new technology, and demonstrate applications of space technology?

(SEE CHART 5-2)

5.1.2 RESEARCH AND DEVELOPMENT

What research, studies, and fundamental investigations are required to support exploitation of space technology for satisfying communications and navigation needs?

(SEE CHART 5-3)

5.1.3 RESOURCE MANAGEMENT

What specialized knowledge is required for regulation and management of the frequency and orbital resources available for communications and navigation services?

(SEE CHART 5-6)

5.2 NAVIGATION/TRAFFIC CONTROL

How may space technology contribute to mankind's needs for precise determination of geographic position of air and oceanic transportation vehicles and provide control of vehicular traffic for routing, collision avoidance, and search and rescue?

5.2.1 SPACE NEEDS

What systems are required for position and trajectory determination of manned space vehicles?

(SEE CHART 5-7)

5.2.2 AIRCRAFT AND MARINE NEEDS

How may space technology enhance safety, efficiency and passenger convenience of airborne and marine transportation vehicles?

(SEE CHART 5-8)

5.2.3 SPACE VEHICLE LAUNCH AND REENTRY NEEDS

What systems are required for safety, traffic control, and vehicle recovery support during space vehicle launch and recovery operations?

(SEE CHART 5-9)

Chart 5-2. Communications – Applications

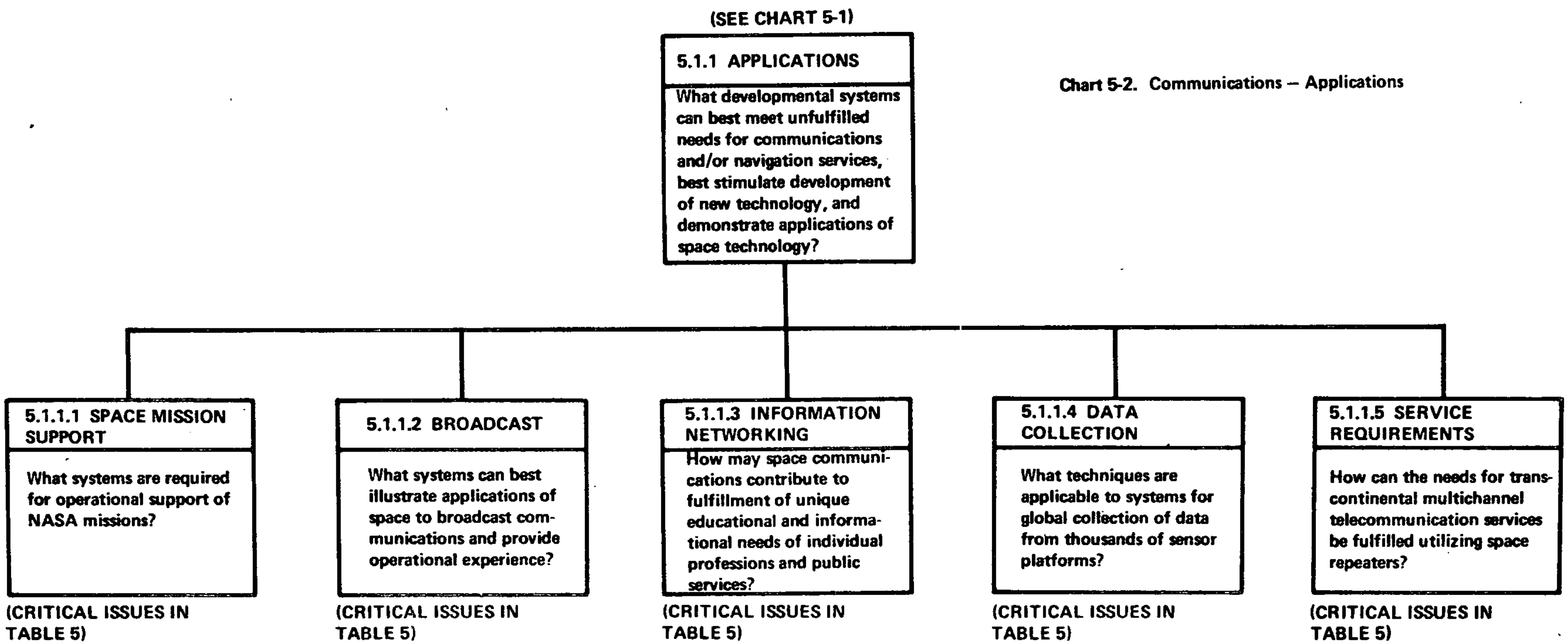
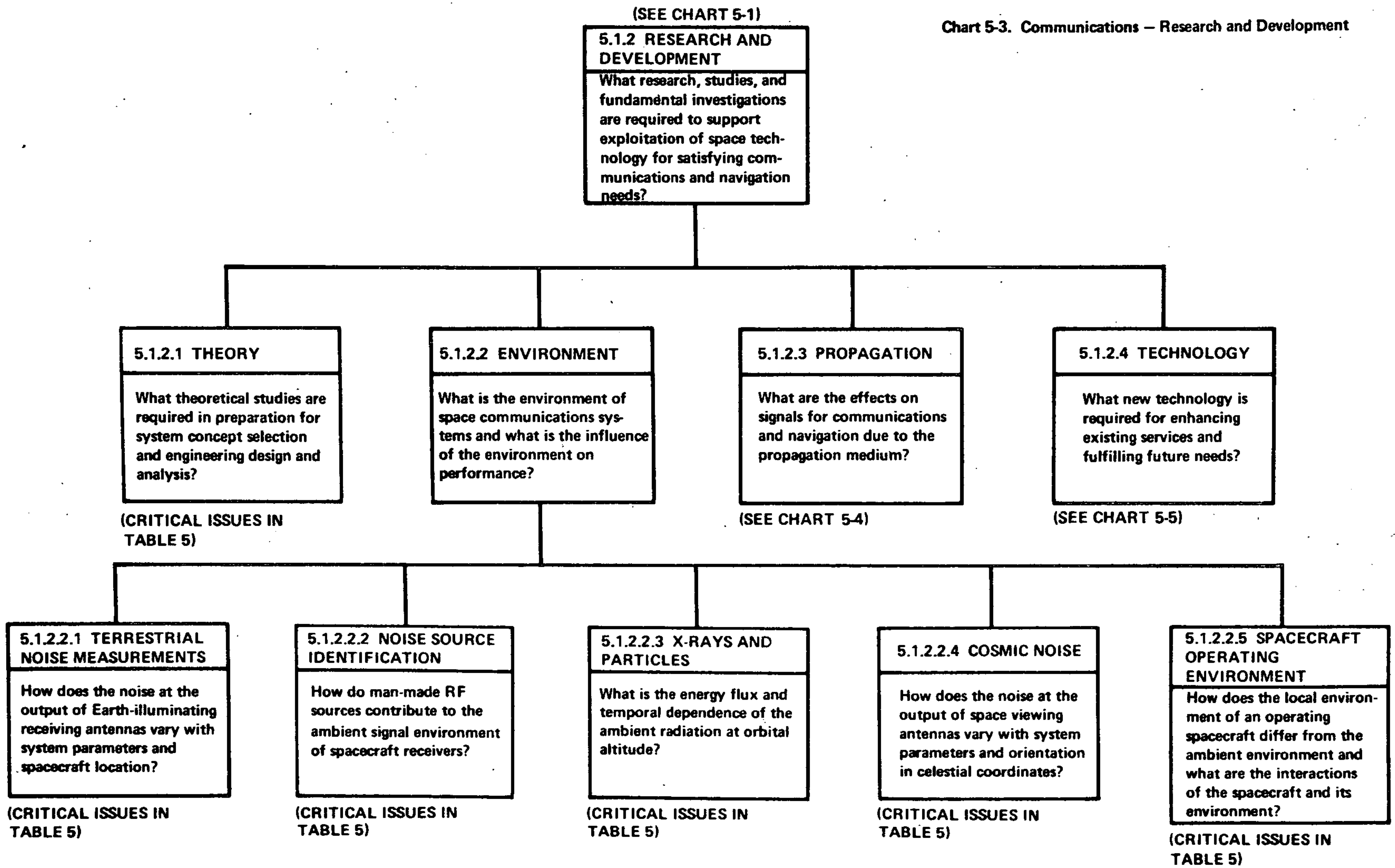


Chart 5-3. Communications – Research and Development



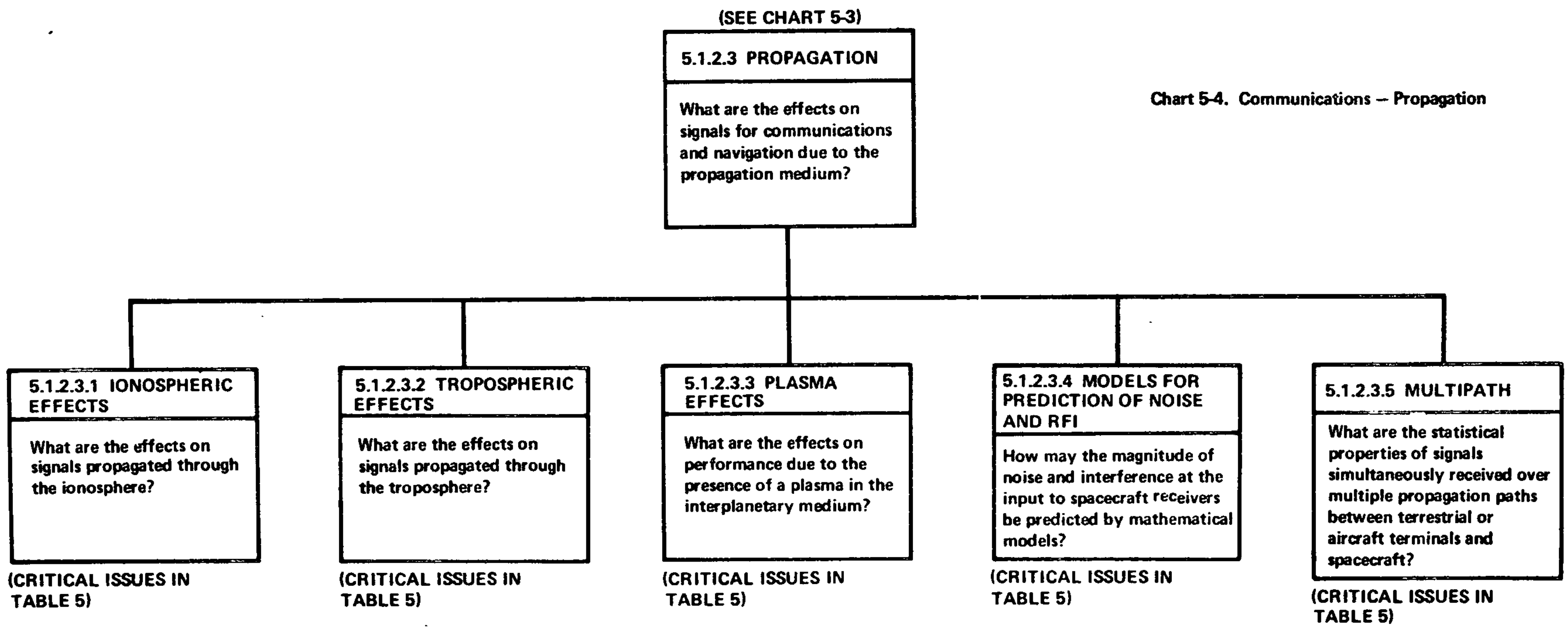


Chart 5-4. Communications – Propagation

Chart 5-5. Communications – Technology

(SEE CHART 5-3)

- **5.1.2.4 TECHNOLOGY**
  What new technology is required for enhancing existing services and fulfilling future needs?
  - **5.1.2.4.1 USER REQUIREMENTS**
    Which novel user requirements for future systems require development of new technology?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.2 SPACECRAFT ANTENNA**
    What characteristics of spacecraft antennas should be emphasized for future development?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.3 LOW-NOISE RECEIVER INPUT STAGE**
    What approaches to low-noise receiver development appear most productive?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.4 TRANSMITTERS**
    What characteristics should be emphasized in transmitter development?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.5 SPACECRAFT MEMORIES**
    What properties should be emphasized in development of spacecraft memories?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.6 ONBOARD SIGNAL PROCESSORS**
    What type of onboard processors can contribute to fulfillment of user requirements?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.7 PASSIVE RF COMPONENTS**
    What characteristics of passive RF components should be emphasized for future development?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.8 PRIMARY POWER SYSTEMS**
    What development in primary power systems are required for future system requirements?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.9 NEW DEVICE APPLICATIONS**
    What limitations on present devices dictate the orientation for future research?
    (NO CRITICAL ISSUES DERIVED)
  - **5.1.2.4.10 LOW-COST SMALL-USER TERMINALS**
    What developments are required to reduce quantity production costs for small-user terminals?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.11 INPUT/OUTPUT DEVICES**
    What improvements in input/output devices are desirable to fulfill requirements of manned space missions?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.12 OTHER SPACECRAFT SUBSYSTEMS**
    What development requirements are imposed on other spacecraft systems by developments in communications technology?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.13 DEVELOPMENT TO SUPPORT EVA**
    What technology developments are required to support extra vehicular activity for manned space missions?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.14 CONTRIBUTIONS OF MANNED SPACE FLIGHT TO TECHNOLOGY DEV**
    How may extra vehicular activity on manned space missions contribute to development of communications technology?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.15 ASTRONAUT SAFETY**
    What precautions may be required for protection of astronauts?
    (CRITICAL ISSUES IN TABLE 5)
  - **5.1.2.4.16 DEMONSTRATION AND TEST**
    What space experiments are required by the technology development program?
    (CRITICAL ISSUES IN TABLE 5)

Chart 5-6. Communications – Resource Management

(SEE CHART 5-1)

5.1.3 RESOURCE MANAGEMENT
What specialized knowledge is required for regulation and management of the frequency and orbital resources available for communications and navigation services?

- **5.1.3.1 FREQUENCY ALLOCATION**
  What is the optimum allocation of the EM spectrum to provide present and future space service requirements?
  (CRITICAL ISSUES IN TABLE 5)
- **5.1.3.2 MM WAVE DEMONSTRATION**
  How may millimeter waves best be employed to meet future requirements for increased spectrum availability?
  (CRITICAL ISSUES IN TABLE 5)
- **5.1.3.3 OPTICAL FREQUENCY**
  How may optical frequencies best be employed to meet future requirements for increased spectrum availability?
  (CRITICAL ISSUES IN TABLE 5)
- **5.1.3.4 FUTURE NEEDS**
  What are 5- and 20-year projections of domestic and global requirements for COMM NAV services?
  (CRITICAL ISSUES IN TABLE 5)
- **5.1.3.5 USAGE AND CONTROL**
  How is the EM spectrum being utilized and how can it be more effectively controlled?
  (CRITICAL ISSUES IN TABLE 5)

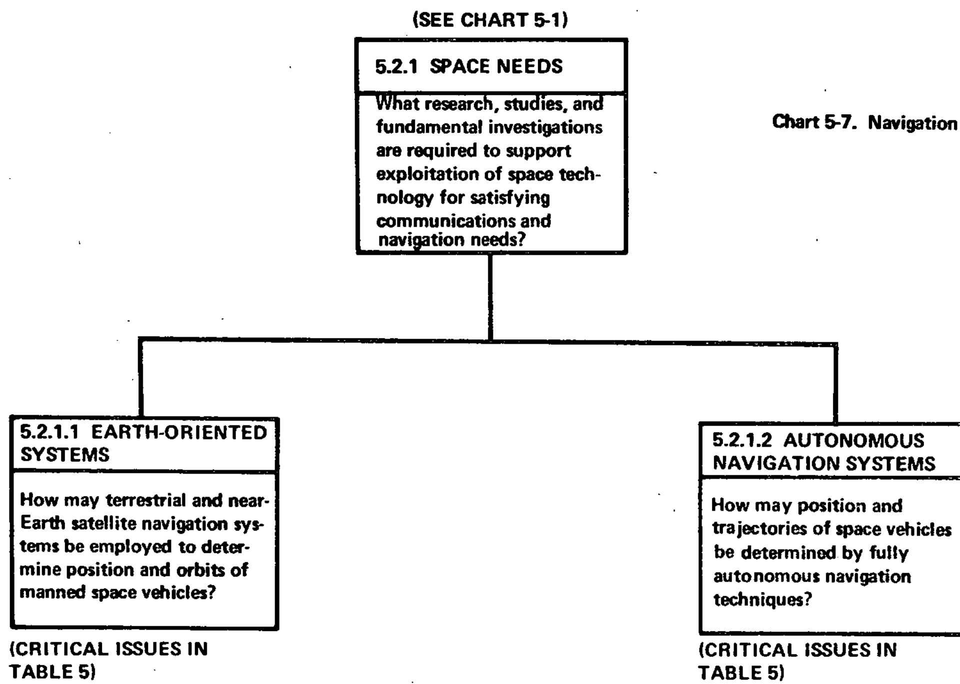


Chart 5-7. Navigation – Space Needs

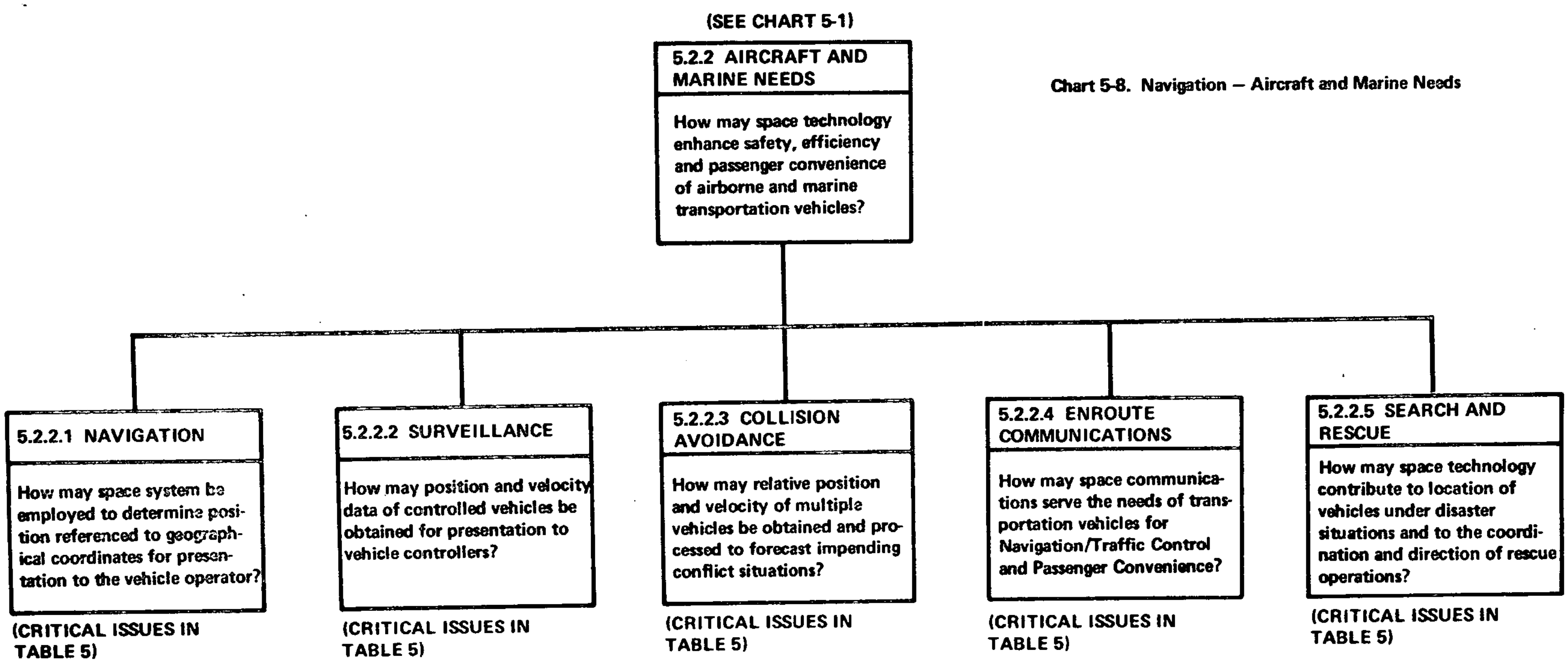


Chart 5-8. Navigation – Aircraft and Marine Needs

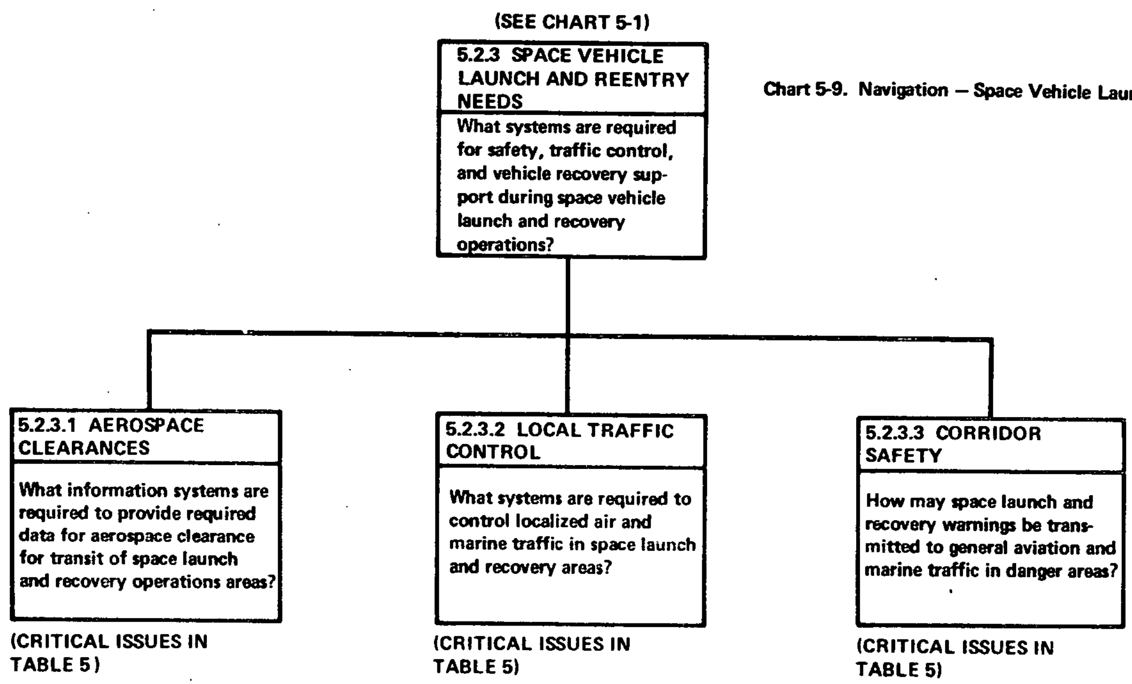


Chart 5-9. Navigation – Space Vehicle Launch and Reentry Needs

APPENDIX B

CRITICAL ISSUES

COMMUNICATIONS AND NAVIGATION

Appendix B
INTRODUCTION

This appendix presents the series of 3,800 critical issues that comprise the principal result of the organized overview analysis of objectives for the six scientific and technical disciplines. The organized overview is described in Section 2 and graphically displayed in the charts contained in Appendix A.

In order to maintain the traceable indexing system carried through the charts shown in Appendix A, the numbers are repeated as major headings in Appendix B. Each critical issue thereby retains identity with the objectives and subobjectives from which it was derived.

The results of further analysis of the critical issues during the latter phases of the study are combined with the tabulation in this appendix by entering a code in the margin of the page, specifying the eventual disposition action. Table B-1 explains the code used for this assignment of critical issues.

In using Table B-1 to trace out the disposition, it is helpful to note that the principal consideration is whether or not the critical issue is addressed in at least one research cluster. In cases where this has occurred, the identifying serial number of the research cluster is used as the code. The alternative (2-letter) codes refer to categorical assignments of critical issues not included in the research cluster descriptions.

A summary of the disposition of the 3,800 critical issues in the six disciplines, according to the coding protocol of Table B-1, is presented in Table B-2.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES

X-AB-YY	<u>Addressed in Research Cluster No. X-AB-XY</u> The first number (X) indicates the scientific or technical discipline, i. e., 1 - Manned Spaceflight Capability 2 - Space Biology 3 - Space Astronomy 4 - Space Physics 5 - Communications and Navigation 6 - Earth Observations The one- or two-letter code (AB) indicates the subdiscipline area, e. g., BR - Behavioral Research PP - Plasma Physics Laboratory A/F - Agriculture, Forest, and Range Resources The final number (YY) is a sequence number within the subdiscipline. Thus, 4-PP-3 is the third research cluster in the Plasma Physics Laboratory subdiscipline of the Space Physics discipline.
PS	<u>Eliminated by Preliminary Screening</u> Critical issue considered to be essentially peripheral to the scope of Earth orbital research. These issues were included in the report for the ideas that they might stimulate, but were not analyzed further.
NS	<u>Eliminated: Not an Earth Orbital Research Candidate</u> Critical issue judged to be more appropriate to research based elsewhere—terrestrial, sub-orbital, interplanetary trajectories, extraterrestrial bodies, etc.—after considering the advantages and disadvantages of various orbits and of the space environment.
UM	<u>Eliminated: Not a Manned Earth Orbital Research Candidate</u> Critical issue judged to be better suited to automated spacecraft than to manned Earth orbital research facilities, due either to the inability of man to contribute meaningfully to the research or to detrimental effects of man's presence.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES (Continued)

OP	<u>Eliminated: Covered in Ongoing Programs</u> Critical issue whose research requirements are expected to be satisfied from the results of programs already in progress or firmly planned.
AC	<u>Deferred, Due to Requirements for Advanced Concepts</u> Critical issue for which no experimental approach is currently available, or for which advanced study or advanced ground-based developments should precede further programmatic analysis.
MS, SB, SA, SP, CN, or EO	<u>Principally Concerned with Another Discipline</u> Critical issue included in the organized overview analysis of a given discipline for the sake of completeness, but which is actually more germain to another discipline (indicated by symbol) and is analyzed further in that discipline.

Table B-2

DISPOSITION OF CRITICAL ISSUES

Code \ Discipline	Manned Spaceflight Capability	Space Biology	Space Astronomy	Space Physics	Communications and Navigation	Earth Observations	Totals
In Research Cluster Cluster (X-AB-YY)	785	361	154	154	90	439	1,983
Preliminary Screening (PS)	330	0	155	15	0	36	536
Not Earth Orbital (NS)	187	0	240	49	81	137	694
Not Manned Earth Orbital (UM)	0	0	21	23	0	35	79
Covered in Ongoing Programs (OP)	72	0	0	0	14	1	87
Requires Advanced Concepts (AC)	81	2	156	0	122	9	370
Referred to Another Discipline (MS, SB, etc.)	13	0	26	3	8	1	51
Totals	1,468	363	752	244	315	658	3,800

Table 5

COMMUNICATIONS AND NAVIGATION CRITICAL ISSUES

5.1 COMMUNICATIONS

5.1.1 APPLICATIONS[1]

1. Rationale: The NASA applications programs generally require an extended period of operational capability, and, hence, in some respects the hardware systems may be regarded as engineering prototypes of operational systems. However, full system procurement is generally not authorized until nearly all questions of technical feasibility have been resolved. Although by some standards the NASA applications programs would be considered as experimental developments, for purposes of this overview they play the role of forcing functions on the R & D program in that they contribute requirements for component and subsystem development. For this reason only generally applicable categories of applications programs are discussed below. A detailed analysis of the requirements implied by these applications can, in principle, justify directly the detailed requirements for space experimentation under Subsection 5. 1. 2, Research and Development. Such a detailed analysis is beyond the scope of this report.

5.1.1.1 Space Mission Support

5.1.1.1.1 Manned Space Flight

What mission support services must be provided for future manned missions?

5.1.1.1.1.1 Service Requirements

What are the qualitative communications services which may be required for future manned missions?[2] OP

2. Discussion: Some or all of the following services may be provided for most future manned missions.
   - Two-way TV.
   - Analogue data.
   - Digital data.

- Two-way voice.
- Position and velocity measurement.
- Subsatellite Control

Quantitative requirements must be established for each mission as the programs are authorized.

The emphasis on low power and weight for space flight will continue to require improvements in technology to provide these services as needs are defined, employing the then-current state of the art.

No significant infusion of technology development or research funding peculiar to service requirements of manned space mission support have been identified.

Commonality: Quantitative service requirements influence the following objectives:

Earth Terminals (5.1.1.1.1.3)

Mission Control Centers (5.1.1.1.1.4)

Mission Data Relay Satellites (5.1.1.1.1.5)

Technology (5.1.2.4)

Frequency Allocation (5.1.3.1)

Future Needs (5.1.3.4).

5.1.1.1.1.2 Mission Identification

What are the general categories of manned missions having significant influence on communications design?[3] OP

---

3. Discussion: Space communicating system requirements will depend on the distances between the transmitter and receiver terminals, the amount and type of data to be transferred, and the degree to which real time or stored data is required. The distribution of the planets and the Earth's moon in the solar system leads to the following classification of missions:

   A. Near-Earth orbits.

   B. Geostationary orbits.

   C. Lunar transfer orbits.

   D. Lunar orbit.

   E. Lunar exploration.

   F. Earth-planet transfer orbits.

   G. Planetary orbit.

   H. Planetary exploration.

Missions A through D can be supported with existing systems and technology.

Commonality: The requirements of missions E through F should be considered in the following objectives:

Technology (5. 1. 2. 4)

Frequency Allocation (5. 1. 3. 1)

MM Wave Demonstration (5. 1. 3. 2)

5.1.1.1.1.3 Earth Terminals

What influence will manned missions have on Earth-terminal design and operational requirements? [4] OP

---

4. Discussion: Examples are:

- Service to multiple missions—If data relay satellites with multiple beam antennas are employed, Earth terminals may service more than one mission at a time.
- Wide bandwidth signal processors—Satellites with multiple sensors and increases in sensor resolution will require wide bandwidths for data transmission. Random access techniques, whether FDMA, TDMA, or CDMA, will generally require signal processing in broad RF bandwidths.
- MM wave components—As X-band and lower frequencies become more congested, frequencies between 10 and 18 GHz will probably be allocated to Earth-space communication links. Low-noise receivers, high-power transmitters and large-diameter antennas with high precision surfaces will be required.

If system compatibility is to be maintained, technology development for Earth terminals must parallel new technology developments for space components. Such technology may originate from Earth terminal developments for space-flight demonstration of new technology.

5.1.1.1.1.4 Mission Control Centers

What are the functional requirements on mission control centers for manned space flight operations? [5] OP

5. Discussion: The mission control center is the communications node at which system consideration for mission operations support may terminate. The mission control center may include store and forward or data relay functions for distribution of data. In these cases the data processing system may be the interface between the mission communications system and an information networking system. (See 5.1.1.3)

Functional elements:

- Mission data display.
- Communications terminal equipment.
- Scientific data management (and processing).
- Computational support.
- Personnel.

5.1.1.1.1.5 Mission Data Relay Satellites

How may data relay satellites be employed in Manned Space Flight Mission Support? [6]

.1 Planetary (or lunar) relay—A lunar or planetary orbiter may relay communications to Earth when the user station is not within line of sight of Earth stations. Experiment requirements: The utility of the lunar libration point should be evaluated by demonstration of the stability of the libration point orbit. 5-TF-1,2 5-CS-1,2

.2 Earth orbiting relay—Geostationary Earth satellites employed as mission data relays can provide nearly continuous coverage of deep-space missions and provide improved angular accuracy for position fixing due to the large baseline for observations. 5-TF-1,2 5-CS-1,2

.3 Cross space relay—Three or four geostationary satellites equally spaced about the equator can provide continuous coverage of both low-orbiting satellites as well as deep-space probes. By the use of 2 cross-space relays to one satellite in view of CONUS, the entire net can be served by one ground station. 5-TF-1,2 5-CS-1,2

6. Discussion:

Development requirement examples related to the data relay satellites are:

Multibeam satellite antennas.

Wideband data modulation.

Random access techniques.

High voltage in space.

Large steerable beam antennas.

MM wave components.

Spacecraft stabilization.

5.1.1.1.1.6 Frequency Allocation Requirements

What are the future requirements for new frequency allocations to provide communications support for manned space missions? [7] OP

---

7. Discussion: Compatibility with other users in the currently assigned frequency bands for Earth-space communications must be reviewed periodically.

   Commonality: Such reviews provide an important input to objectives 5.1.3.1 and 5.1.3.4. Critical Issue 5.1.1.1.1.6, together with 5.1.2.2, Environment, leads to the definition of technology and experimental requirements.

5.1.1.1.1.7 Spacecraft Input/Output Devices

What spacecraft communications terminal equipment is required for manned space flight communications? [8] OP

---

8. Discussion: Examples are:

   - Signal processors for automated experiments and house-keeping data. (See 5.1.2.4.6.)
   - Tape recorders for temporary data storage. (See 5.1.2.4.5 and 5.1.2.4.13.)
   - Video displays. Near term: CRT. Future: Solid State displays. (See 5.1.2.4.11.)
   - Digital message composers. Teletype or special keyboard for entry of subjective observations. (See 5.1.2.4.11.)
   - Vidicons. (See 5.1.2.4.11.)
   - Microphones. (See 5.1.2.4.13.)
   - Headsets and loudspeakers. (See 5.1.2.4.13.)
   - Local relay for extra-vehicular activity. (See 5.1.2.4.13.)

   In addition to normal telemetry, the presence of man requires special audio and visual input and output devices, which are not required in automated spacecraft.

   Commonality: This requirement must be analyzed for each mission and will provide a continuing input to the objectives of 5.1.2.4, Technology.

5.1.1.1.2 Near-Earth Experiments

What are the communications requirements for support of unmanned near-Earth-orbit dedicated satellites? OP

5.1.1.1.3 Lunar Missions

What are the communications requirements for support of automated spacecraft for lunar missions? OP

5.1.1.1.4 Planetary Missions

What are the communications requirements for support of automated spacecraft for planetary missions? OP

5.1.1.1.5 Ground Systems

What are the requirements on Earth systems for support of NASA missions? OP

5.1.1.1.6 Observatory Satellites

What are the communications requirements for support of large automated observatory satellites in Earth orbit? OP

5.1.1.1.7 Satellite Data Relay

How may data relay satellites be employed in support of NASA missions? OP

5.1.1.2 Broadcast

What systems can best illustrate applications of space to broadcast communications and provide operational experience?

5.1.1.2.1 Special Interest TV 5-TF-1,2

5.1.1.2.2 Educational TV 5-TF-1,2

5.1.1.2.3 Teleclub Systems 5-TF-1,2

5.1.1.2.4 TV Distribution AC

5.1.1.2.5 Direct TV to Homes 5-TF-1,2

5.1.1.3 <u>Information Networking</u>

How may space communications contribute to fulfillment of unique educational and informational needs of individual professions and public services?

5.1.1.3.1 Connection of Major Regional Centers (libraries) 5-TF-1,2

5.1.1.3.2 Communication Between Major Centers and Geographical Areas With Poorly Developed Communications 5-TF-1,2

5.1.1.3.3 Distribution of Educational TV Programming NS

5.1.1.3.4 Transmission of High-Resolution Images Such as X-Ray Photos 5-TF-1,2

5.1.1.3.5 Interrogation of Remote Time-Sharing Computers AC

5.1.1.4 <u>Data Collection</u>

What techniques are applicable to systems for global collection of data from thousands of sensor platforms?

5.1.1.4.1 Store-and-Forward Memories For Satellites (Millions of Bits) 5-TF-1,2

5.1.1.4.2 Coding and Random Access Techniques for Platform Interrogation AC

5.1.1.4.3 Modulation Techniques for Data Transfer From Collection Satellites-to-Ground Stations AC

5.1.1.4.4 Mobile Platform Location Techniques (2 km accuracy) AC

5.1.1.4.5 Low Cost User Platform and Sensor Equipment AC

5.1.1.4.6 Ground Data Processing Equipment AC

5.1.1.5 Service Requirements

How can the needs for transcontinental multichannel telecommunication services be fulfilled utilizing space repeaters? [9]

---

9. Rationale: Although it is recognized that this research objective may be the responsibility of an agency, other than NASA, which would conduct its own R&D program, it is included in this overview to emphasize the commonality of research objectives and technology and the potential competition for frequency bands and spacecraft resources. Particularly in the NASA objective of 5.1.3, Resource Management, the requirements of the common carriers must receive consideration. In the objective of 5.1.2.4, Technology, economic benefits will undoubtedly accrue to each organization through the development activities of the other.

5.1.1.5.1 Services

What services are presently provided by the commercial common carriers that might be provided by satellite point-to-point links? [10] AC

---

10. Discussion: Such services include:
    - Two-way voice (telephone).
    - Facsimile.
    - Business Data.
    - Teletype.
    - Video (TV).

5.1.1.5.2 Modulation Techniques

To what extent may the employment of alternative modulation techniques reduce loss of circuit quality due to interference? AC

5.1.1.5.3 Constraints

Are modulating and multiplexing techniques suitable for space communications compatible with existing communications without extensive signal processing modifications? AC

5.1.1.5.4 Technology

Are there any unique technology requirements for this application that do not result from R&D for applications programs included under the objectives of 5.1.1.1 through 5.1.1.4? AC

5.1.2 RESEARCH AND DEVELOPMENT

5.1.2.1 Theory

What theoretical studies are required in preparation for system concept selection and engineering design and analysis? [11]

---

11. Rationale: A section on theory is included here to emphasize the novelty of some of the problems inherent in many of the potential applications of space technology to Communications and Navigation and also to stress the need for a continuing interaction between theoretical analysis and the design and performance of experiments. The listings below are intended as a partial identification of research objectives which are currently under active theoretical investigation. In many instances the applicable theory will not be unique to space technology.

5.1.2.1.1 User Requirements

Which novel user requirements for future systems require theoretical studies?

.1 Network access requirements. (See 5.1.2.4.1.1.) NS
.2 Circuit multiplexing requirements. (See 5.1.2.4.1.2.) NS
.3 Circuit quality requirements. (See 5.1.2.4.1.3.) NS
.4 Compatibility requirements. (See 5.1.2.4.1.4.) NS

.5 User terminal equipment constraints. (See 5.1.2.4.1.5.) NS

.6 System availability requirements. (See 5.1.2.4.1.6.) NS

.7 Combined position determination and communication requirements. (See 5.1.2.4.1.7.) NS

.8 Related objectives. (See 5.1.2.4.1.8.) NS

5.1.2.1.2 Signal Design Techniques Analysis

How may various signal design techniques contribute to satisfaction of user requirements?

.1 Information modulation techniques (supports 5.1.2.4.6). AC

.2 Demodulation techniques (supports 5.1.2.4.6). AC

.3 Signals for position location (supports 5.2.1 and 5.2.2). AC

.4 Detection techniques for position location (supports 5.2.1 and 5.2.2). AC

.5 Diversity techniques. (See 5.1.2.3.5 and 5.2.2.) AC

5.1.2.1.3 Ambient Signal Environment Models

How may noise and interference at the receiver input be represented methematically? (A possible approach to model development is described in 5.1.2.3.4.) AC

5.1.2.1.4 Performance Analysis

What is the theoretical performance of various applicable combinations of signal design, demodulation techniques, and signal environment? (This supports all development programs and also relates to 5.1.2.2 and 5.1.2.3.) AC

5.1.2.1.5 Propagation Models

How may the various modes of propagation of noise and interference between sources and the system receiver and the multipath effects be represented mathematically? (See also 5.1.2.3.4.5 and 5.1.2.3.4.6.) AC

5.1.2.1.6 Information Processing

What signal processing prior to transmission can contribute to fulfillment of user requirements?

.1 Averaging. AC
.2 Redundancy reduction. AC
.3 Coding (supports 5.1.2.4.6). AC

5.1.2.2 Environment

5.1.2.2.1 Terrestrial Noise Measurements

5.1.2.2.1.1 Frequency Dependence

How does the output noise power of Earth-illuminating receiving antennas depend upon the center of the received frequency band? 5-N-1,-2 5-TF-1

5.1.2.2.1.2 Geographic Dependence

How does the output noise power of Earth-illuminating receiving antennas depend upon the geographic coordinates of the area viewed by the antenna? 5-N-1,-2 5-TF-1

5.1.2.2.1.3 Temporal Dependence

How does the output noise power of Earth-illuminating receiving antennas depend upon local time at the area viewed by the receiving antenna? 5-N-1,-2 5-TF-1

5.1.2.2.1.4 Amplitude Statistics

What is the short term distribution of noise voltage relative to the root-mean-square noise power at the output of Earth-illuminating receiving antennas? 5-N-1,-2 5-TF-1

5.1.2.2.2 Noise Source Identification

5.1.2.2.2.1 Transmitter Signatures

What is the output power spectrum of transmitters operating within or near frequency bands utilized by space communications and navigation systems? AC

5.1.2.2.2.2 Spurious Radiation

What is the electromagnetic radiation of radio transmitters and electrical machinery outside of authorized emission bands? AC

5.1.2.2.2.3 Information Monitoring

How can aural or visual monitoring of received interfering signals significantly contribute to identification of man-made noise sources? 5-N-2 5-TF-2

5.1.2.2.2.4 Radio Direction Finding (RDF) Techniques

How can RDF techniques contribute significantly to identification of interfering man-made noise sources? 5-N-2

5.1.2.2.2.5 Data Processing

How can data processing of ambient noise contribute to identification of man-made noise sources? AC

5.1.2.2.2.6 Related Objectives

What other objectives of NASA and other government agencies should be considered in design of noise measurement experiments? OP

5.1.2.2.2.6.1 NASA Objectives

What other NASA objectives should be considered in design of noise measurement experiments? [12] OP

12. Commonality: The following listing of objectives from this overview should be considered during experiment design:

Space Mission Support. (5. 1. 1. 1)

Broadcast. (5. 1. 1. 2)

Information Network. (5. 1. 1. 3)

Data Collection. (5. 1. 1. 4)

Signal Design Techniques Analysis. (5. 1. 2. 1. 2)

Ambient Signal Environment Models. (5. 1. 2. 1. 3)

Propagation Models. (5. 1. 2. 1. 5)

Propagation. (5. 1. 2. 3)

Models for Prediction of Noise and RFI. (5. 1. 2. 3. 4)

Frequency Allocation. (5. 1. 3. 1)

Future Needs. (5. 1. 3. 4)

Usage and Control. (5. 1. 3. 5)

Aircraft and Marine Needs. (5. 2. 2)

5. 1. 2. 2. 2. 6. 2 Military Space Program Objectives

What is the appropriate distribution of responsibility between NASA and the military space program to (1) prevent duplication of experiments, (2) cross-fertilize military and civilian technology, (3) protect national security, and (4) prevent interference between military and civilian space communications and navigation systems? NS

5. 1. 2. 2. 2. 6. 3 National Security Objectives

How can the security of friendly military transmissions be protected during the accumulation of experimental data? NS

5. 1. 2. 2. 2. 6. 4 Electronic Intelligence Objectives

How may RFI survey data be generated and distributed without compromising U. S. capability in electronic intelligence? NS

5.1.2.2.3 X-Rays and Particles

What is the energy flux and temporal dependence of the ambient radiation at orbital altitude? [13]

---

13. Rationale: Although the following four measurements are more appropriate to physics experiments of the space environment, they are identified here as sources of engineering data required for environmental specification necessary to spacecraft component design and development.

5.1.2.2.3.1 Event Counters

How does the number of discrete events per unit area per second, or per unit solid angle per second, vary with spacecraft orbital altitude? SP

5.1.2.2.3.2 Ionization Measurements

How does the total dosage per unit volume of various materials depend upon spacecraft orbital altitude? SP

5.1.2.2.3.3 Plasma Density Measurements

What is the temporal and spacial dependence of plasma density? SP

5.1.2.2.3.4 Measurements Under Radiation Shields

How do the event rate and the total dosage vary with the thickness and materials of shields surrounding the detection devices? SP

5.1.2.2.4 Cosmic Noise

5.1.2.2.4.1 Frequency Dependence

How does the output noise power of space-illuminating receiving antennas depend upon the center of the received frequency band? SP

5.1.2.2.4.2 Spatial (Celestial Coordinates) Dependence

How does the output noise power of space-illuminating receiving antennas depend upon the celestial coordinates of the solid angle illuminated by the antenna? SP

5.1.2.2.4.3 Temporal Dependence

How does the received noise power at a given frequency and in a given direction vary as a function of time? SP

5.1.2.2.4.4 Polarization Dependence

What is the correlation between power received at orthogonal polarizations at a given frequency and in a given direction? SP

5.1.2.2.5 Spacecraft Operating Environment

5.1.2.2.5.1 Pressure

How does pressure change as a function of time in vented enclosures in an operating spacecraft? 5-TF-2

5.1.2.2.5.2 Charge Density

What is the conductivity, DC breakdown voltage, and RF breakdown voltage of the ambient medium in vented enclosures and in the immediate vicinity of an operating spacecraft? 5-P-3 5-TF-1,2

5.1.2.2.5.3 Temperature

What is the operating temperature of electronic equipment aboard spacecraft? 5-TF-1,2

5.1.2.2.5.4 Change in Properties of Materiels

How do physical and electrical properties of materials of communication equipment change during operation in the space environment? 5-TF-2

5.1.2.2.5.5 Electromagnetic Radiations of Spacecraft Systems

Are conducting and radiating electric fields and currents generated by other subsystems of the spacecraft sufficiently low to have negligible influence on performance of the communications components? [14] 5-TF-1,2

---

14. Discussion: This objective is appropriately satisfied for individual spacecraft through RFI compatibility specification and through system integration tests prior to launch.

5.1.2.2.5.6 Meteorite Bombardment

What is the rate of erosion of exposed components due to meteorite bombardment? 5-TF-1

5.1.2.3 Propagation

What are the effects on signals for communications and navigation due to the propagation medium? [15]

---

15. Rationale: For most applications, propagation is not a limitation on space communications and navigation systems, although the statistical properties of the medium do place fundamental limitations on the accuracy of position location systems and may ultimately limit the performance of extremely high data rate systems. For general applicability, the following outline follows the classical division of the regions traversed by signals employed in space communications. In practice, signals will traverse more than one of the regions and the total effect is of interest to system designers. The objectives of experimentation should be to derive probability distributions of signal parameters (e.g. path loss, polarization rotation, diffraction, phase stability, and propagation delay) which will provide inputs to system analysis and also may be compared to the statistical models of the medium.

5.1.2.3.1 Ionospheric Effects

5.1.2.3.1.1 Attenuation

How does signal strength from a satellite in synchronous orbit depend upon ground station location and ionospheric conditions as determined by conventional ionospheric sounders as a function of frequency? (This is of increasing importance as frequency decreases below VHF.) 5-P-1 5-TF-1,2

5.1.2.3.1.2 Refraction

How does the apparent angle of arrival of signals propagated through the ionosphere vary as a function of time and frequency? Can the statistics be predicted from ionospheric sounder or solar wind date? 5-P-1 5-TF-1,2

5.1.2.3.1.3 Polarization Rotation

After passage of a signal through the ionosphere, what is the probability distribution of the polarization vector of the signal from a linearly polarized transmitting antenna? Can the statistics be predicted or correlated with ionospheric sounder or solar wind data? 5-P-1 5-TF-1,2

5.1.2.3.1.4 Mixing of Signals

The interaction of two signals passing through an ionized medium in a magnetic field produces sum and difference frequency signals. What is the magnitude of the mixed components and what is the contribution of this effect to the ambient noise? 5-P-1 5-TF-1,2

5.1.2.3.1.5 Spatial and Time Variations

At frequencies that are significantly influenced by the ionosphere how do the statistics of signals observed as described above vary with local time and within geomagnetic latitude and longitude differences between a satellite and an Earth terminal? 5-P-1 5-TF-1,2

5.1.2.3.1.6 Time Spreading

Many observed phenomena are currently explained by ascription of a time and spacial density structure to the ionosphere, resulting in signal components received over multiple paths at slightly varying times. What is the distribution in the arrival time about the nominal time of pulse signals when referred to a stable clock? 5-P-1 5-TF-1,2

5.1.2.3.1.7 Frequency Spreading

A time-varying ionospheric structure as described in 5.1.2.3.1.6 will contribute a measurable spreading of a signal in the frequency domain. What is the distribution of phase noise in a signal derived from a stable oscillator? 5-P-1 5-TF-1,2

5.1.2.3.1.8 Partial Reflection

The classical model of HF skywave propagation treats the ionosphere as stratified layers of differing index of refraction, with structure when necessary to explain certain observed phenomena. What is the ratio of signal strength reflected in various skywaves to the signal strength transmitted completely through the ionosphere and how do the reflection coefficients depend on frequency? 5-P-1 5-TF-1,2

5.1.2.3.2 Tropospheric Effects

5.1.2.3.2.1 Clear Air Attenuation

What is the path loss between ground terminals and spacecraft as a function of frequency (range of measurements: 1 MHz to 100 GHz) with no visible clouds or rain in the line-of-sight transmission path, and how may variations from the mean path loss be related to, or predicted by, meteorologic data? 5-P-2 5-TF-1,2

5.1.2.3.2.2 Attenuation by Clouds

What is the relationship between path loss through clouds of various types as a function of frequency? Can path loss be statistically predicted from meteorologic data? 5-P-2 5-TF-1,2

5.1.2.3.2.3 Rainfall Attenuation

What is the probability distribution of path loss as a function of frequency during rainy weather and how may margin requirements be derived from meteorologic data? 5-P-2 5-TF-1,2

5.1.2.3.2.4 Refraction

What is the relationship between meteorologic observations and the mean angle of arrival of signal between a ground station and a spacecraft and what is the probability distribution of angle of arrival about the mean value? 5-P-2 5-TF-1,2

5.1.2.3.2.5 Time Spreading

What is the probability distribution in arrival time about the mean time delay of signals propagated through the troposphere and how may the time spreading be related to, or predicted from, meteorologic data? 5-P-2 5-TF-1,2

5.1.2.3.2.6 Frequency Spreading

What is the frequency (or phase) uncertainty in signals referred to a stable oscillator due to index of refraction variations in the troposphere and how may it be related to, or predicted from, meteorologic data? 5-P-2 5-TF-1,2

5.1.2.3.2.7 Spatial and Time Variance

When the phenonomena discussed under 5.1.2.3.2.1 through 5.1.2.3.2.6 are best described as stochastic processes, what Earth terminal separations are required to ensure that the variables are uncorrelated? Over what time intervals may the processes be considered as time stationary? 5-P-2 5-TF-1,2

5.1.2.3.2.8 Reflection Coefficients

Under meteorological conditions resulting in a highly stratified index of refraction, what is the reflection coefficient as a function of frequency for angles of incidence smaller than the critical angle? Under what meteorological conditions is total reflection encountered? 5-P-2 5-TF-1,2

5.1.2.3.3. Plasma Effects

5.1.2.3.3.1 Signal Attenuation by Plasma

For what frequencies and vehicle orbits does the plasma of interplanetary space produce appreciable attenuation of EM waves? 5-P-3 5-TF-1,2

5.1.2.3.3.2 Polarization Rotation

For what frequencies and vehicle orbits are polarization rotations by the interplanetary medium significant? 5-P-3 5-TF-1,2

5.1.2.3.3.3 DC Breakdown Potentials

In some circumstances spacecraft design may be simplified if high-voltage power supplies and transmitters could be operated in the vacuum of space. What are the DC breakdown potentials versus gap size of various trajectories of interest? 5-P-3 5-TF-1,2

5.1.2.3.3.4 RF Breakdown Fields

The design of feed structures of antennas for transmission of high RF power as well as the physical layout of transmitter elements exposed to the vacuum of space requires detailed information on RF breakdown in orbit. What are the RF breakdown field limitations for various trajectories of interest versus gap size? 5-P-3 5-TF-1,2

5.1.2.3.3.5 Spatial and Time Variance

The phenomena of 5.1.2.3.3.1 through 5.1.2.3.3.4 may have a dependence on the solar wind in the vicinity of the spacecraft and hence will be correlated with solar activity. How do plasma-related effects vary with time and spacecraft location? Can the magnitude of the phenomena be predicted from solar observations? 5-P-3 5-TF-1,2

5.1.2.3.3.6 Plasma Related Propagation Anomalies

The prediction of plasma effects on communication signals is currently based on incomplete knowledge of the physics of the interplanetary medium. Are propagation anomolies present which can only be explained by more complex models of the propagation path? 5-P-3 5-TF-1,2

5.1.2.3.4 Models for Prediction of Noise and RFI

How may the magnitude of noise and interference at the input to spacecraft receivers be predicted by mathematical models? [16]

---

16. Rationale: Whereas 5.1.2.2.1 is concerned with the observation of instantaneous noise and interference signal magnitudes and 5.1.2.2.2 is concerned with the identification of discrete contributers to the total instantaneous noise environments, the prediction of signal environment will require the development of mathematical models which may then be employed for the development of specifications for future space communications and navigation systems.

5.1.2.3.4.1 Geographical Distribution of Sources

May centers of population be represented for interference prediction purposes as statistical distributions of radiating sources, which would be applicable on a regional or national basis? In what frequency bands would such average models be applicable? How may such models represent emitter density as functions of population size, presence of electronics development centers, existence of nearby military bases, and rate of economic growth? AC

5.1.2.3.4.2 Probability of Operation Versus Time

In each contributing frequency band what are the ratios of number of emitters (1) in continuous operation, to (2) those whose operation is random at certain times of day, to (3) those whose operation is random but equiprobable over a 24-hour period? AC

5.1.2.3.4.3 Radiated Energy Frequency Distribution

Which RFI models (as in 5.1.2.3.4.1) would be useful in predicting the appropriate distribution of interference power density as a function of frequency? What statistics are required to describe the signal environment in various segments of the frequency band(e.g., mean power, power variance, higher order moments, or probability of envelope exceeding a multiple of the mean power)? AC

5.1.2.3.4.4 Angular Distribution of Radiated Energy

Is the RFI from a center of population, when viewed from a great distance, a function of the angular coordinates at the center from which it is How does local terrain influence RFI as seen from space? AC

5.1.2.3.4.5 Probability Distribution of Anomolous Propagation Modes

Significant over-the-horizon propagation is observed due to both ionospheric and tropospheric effects. What is the relative contribution on a statistical basis to RFI received over line-of-sight propagation paths? AC

5.1.2.3.4.6 Interference Prediction by Summation of Contributions

Research objectives 5.1.2.3.4.1 through 5.1.2.3.4.5 may be considered as elementary statistical models of source areas and propagation modes which contribute to spacecraft signal environment. What are the appropriate rules of combination of the elementary models for computation of spacecraft signal environment? Do such statistical models taken on a time-averaged basis better represent the signal environment than models developed by identification, location, and cataloguing of individual radiators? AC

5.1.2.3.4.7 Comparison with Observations

Can the results of the computations suggested in 5.1.2.3.4.6 be used in the prediction of actual observations for space? (See research objective 5.1.2.2.1.) 5-N-2 5-TF-1

5.1.2.3.4.8 Iteration of Model Development

How may the model parameters or the rules for combination of elementary models be modified to improve the agreement with RFI measurements in space? AC

5.1.2.3.5 Multipath Effects

5.1.2.3.5.1 Dependence on Terminal Altitude

How do fading rate and depth of fades depend upon the altitude of an aircraft in communication with a spacecraft? 5-P-4 5-TF-1,2

5.1.2.3.5.2 Magnitude vs Terrain

What are the specular and random fading components of multipath signals for various types of terrain overflown by an aircraft for space communications links? 5-P-4 5-TF-1,2

5.1.2.3.5.3 Magnitude vs Elevation Angle Dependence

What is the dependence on elevation angle of the satellite from the aircraft of the specular and random components of multipath signals? 5-P-4 5-TF-1,2

5.1.2.3.5.4 Frequency Dependence

How do fading statistics depend on the selection of carrier frequency? 5-P-4 5-TF-1,2

5.1.2.3.5.5 Amplitude Statistics of Fading

What is the probability for a multipath signal to exceed any given fraction of the single-path free-space signal under various combinations of 5.1.2.3.5.1 through 5.1.2.3.5.4? 5-P-4 5-TF-1,2

5.1.2.3.5.6 Time Statistics

What is the probability distribution of the envelope being less than a given fraction of the single path free space signal versus the time duration of the fade? 5-P-4 5-TF-1,-2

5.1.2.3.5.7 Fading Correlation of Two Signals

What is the minimum separation of two signals for which multipath fading is uncorrelated? 5-P-4 5-TF-1,-2

5.1.2.4 Technology

5.1.2.4.1 User Requirements

Which novel user requirements for future systems require development of new technology? [17]

---

17. Rationale: The following general listing of ten user requirements emphasize those characteristics of future systems which appear at this time to be the most demanding when viewed in the light of state-of-the-art components. Such a list of requirements must be developed for each procurement and must reflect technology representative of the time frame of the procurement. In a general overview such a list can only be representative of questions to be answered. As quantitative statements of system requirements in procurement specifications, such questions become critical issues for the system under consideration.

5.1.2.4.1.1 Network Access Requirements

Are the number of users and the amount of traffic per user such that random access or novel multiple access techniques are more appropriate than clear channel assignments and closely controlled circuit discipline? NS

5.1.2.4.1.2 Circuit Multiplexing Requirements

Is the network configuration such that several single-user circuits should be multiplexed at one or more nodes of the system? If random access is NS required, how can this be accomplished economically while use of the frequency spectrum is conserved?

5.1.2.4.1.3 Circuit Quality Requirements

What is the minimum circuit quality (output bit error rate or signal-to-noise ratio) that will fulfill the needs of system subscribers? Are different operating modes of poorer quality circuits permissible? If so, what is the permissible limit in degradation? NS

5.1.2.4.1.4 Compatibility Requirements

Are there limitations on techniques, system parameters, or system envelope due to requirements to interface with other systems? If there a logistics and/or supply problem that restricts component selection? NS

5.1.2.4.1.5 User Terminal Equipment Constraints

Does a requirement to supply user terminal equipment which is economical and simple dictate a large and expensive space component to optimize overall system cost? NS

5.1.2.4.1.6 System Availability Requirements

For what maximum time per year may a system be out because of component failure, maintenance, or propagation problems? NS

5.1.2.4.1.7 Combined Service Requirements

Are combinations of digital data transmission, analogue data transmission, voice communication, video transmission, and/or position location required for one or more links of the system? NS

5.1.2.4.1.8 User Data Rate Requirements

Do one or more users have a requirement for very high data rate (greater than 5×10^7 bits per second) transmission?

5.1.2.4.1.9 Frequency Allocation

NS

Can the system requirements be met by existing frequency allocations, or must hardware be developed for experimental bands?

5.1.2.4.1.10 Related Objectives

NS

What other objectives of NASA and other government agencies should be considered in selection of technology items for development and demonstration?

5.1.2.4.1.10.1 NASA Objectives

NS

What other NASA objectives should be considered in selection of new technology items for development and demonstration?[18]

---

18. Commonality:
Space Mission Support. (5.1.1.1)
Broadcast. (5.1.1.2)
Information Network. (5.1.1.3)
Data Collection. (5.1.1.4)
Service Requirements. (5.1.1.5)
Theory. (5.1.2.1)
Frequency Allocation. (5.1.3.1)
MM Wave Demonstration. (5.1.3.2)
Optical Frequency. (5.1.3.3)
Future Needs. (5.1.3.4)
Earth-Oriented Systems. (5.2.1.1)
Autonomous Navigation Systems. (5.2.1.2)
Aircraft and Marine Needs. (5.2.2)
Space Vehicle Launch and Reentry Needs. (5.2.3)

5.1.2.4.1.10.2 Military Space Program Objectives

How may technology development under military space programs contribute to fulfillment of NASA objectives and prevent unnecessary duplication of development funding? NS

5.1.2.4.1.10.3 COMSAT CORP Objectives

Can unnecessary duplication of development resource expenditure be prevented by correlation of the NASA and COMSAT CORP Research and Development objectives? NS

5.1.2.4.2 Spacecraft Antenna

What characteristics of spacecraft antennas should be emphasized for future development?[19]

---

19. Rationale: The aforementioned antenna characteristics are representative of general properties that are of current interest in advanced applications of space communications. Any single development and demonstration demands a unique selection of these characteristics such that incremental improvements in spacecraft antenna technology will occur. The critical issue in this requirement is to provide for evolutionary systematic growth in the technology so that the individual characteristics identified do not become pacing items in some future system and to demonstrate new technology through testing in space.

5.1.2.4.2.1 Large Aperture Antennas 5-TF-1

5.1.2.4.2.2 Multiple Transmitting And Receiving Beams 5-TF-1

5.1.2.4.2.3 Wide Bandwidth Antennas AC

5.1.2.4.2.4 Interferometer Structures 5-TF-1

5.1.2.4.2.5 Phased Array Antennas 5-TF-1

5.1.2.4.2.6 Frequency[20] AC

20. Discussion: Examples are:
    - VHF.
    - UHF.
    - SHF.
    - EHF.
    - IR Receiving and transmitting apertures.
    - Optical frequency receiving and transmitting apertures.

5.1.2.4.3 Low Noise Receiver Input Stage

What approaches to low noise receiver development appear most productive?[21]

21. Rationale: The aforementioned listing of technologies applicable to receiver front ends is not necessarily exhaustive and will require future expansion to encompass future inventions or discoveries. No single technique is applicable to all frequencies of interest. The critical issue in this requirement is to provide for evolutionary systematic growth in receiver technology in anticipation of future requirements and to demonstrate developments through space testing.

5.1.2.4.3.1 Masers AC

5.1.2.4.3.2 Diode Mixers AC

5.1.2.4.3.3 Tunnel Diodes AC

5.1.2.4.3.4 Gridded Tubes AC

5.1.2.4.3.5 New Solid State Devices AC

5.1.2.4.3.6 Photo Multipliers AC

5.1.2.4.4 Transmitters

What characteristics should be emphasized in transmitter development?[22]

---

22. Rationale: The present philosophy in spacecraft design is to tailor transmitter design employing available components to system requirements and then achieve acceptable overall system performance through compromises involving many spacecraft subsystems. There is no reason to expect a change in this design approach within the foreseeable future. A number of the requirements identifiable within Subsection 5.1.1, Applications, and 5.2.2, Aircraft and Marine Needs, can only be fully achieved through major improvements in spacecraft transmitter efficiency. This improvement may come about both through component (tube) development and through development of new amplifier circuits. No single device or circuit is generally applicable at the various frequencies of interest, at all power levels, or for all signal modulation techniques. The critical issue in this requirement is to continuously upgrade proficiency in this technology and to demonstrate developments through space testing. The aforementioned listing identifies some of the areas within which a need for improvement is known.

5.1.2.4.4.1 Low Power (<1 watt) AC

5.1.2.4.4.2 Moderate Power ($1 < P_o < 10$ watts) AC

5.1.2.4.4.3 Intermediate Power ($10 < P_o < 100$ watts) AC

5.1.2.4.4.4 High Power ($P_o > 100$ watts) AC

5.1.2.4.4.5 DC to RF Efficiency AC

5.1.2.4.4.6 Transmitter Linearity AC

5.1.2.4.4.7 Wide Bandwidth Transmitters AC

5.1.2.4.5 Spacecraft Memories

What properties should be emphasized in development of spacecraft memories?[23]

23. Rationale: Memory technology for spacecraft is firmly based on that required for terrestrial data processing systems except for the unique packaging requirements of space flight. The critical issue in this requirement is the flight qualification and demonstration (by incorporation as elements of applications programs) and advances in memory device technology. The aforementioned listing of memory characteristics emphasizes some of the more difficult requirements of programs which are presently identified.

5.1.2.4.5.1 Bulk Data Storage AC

5.1.2.4.5.2 Rapid Data Access AC

5.1.2.4.5.3 Non-destructive Readout AC

5.1.2.4.5.4 Different Rates for "Write" And "Read" AC

5.1.2.4.5.5 High Storage Density AC

5.1.2.4.5.6 High Capacity Memories AC

5.1.2.4.5.7 Demonstration Of Interface Between Memory And Signal Processing AC

5.1.2.4.5.8 Demonstration Of Interface Between Control Subsystem(s) And Memory AC

5.1.2.4.6 Onboard Signal Processors

What type of onboard processors can contribute to fulfillment of user requirements?[24.]

24. Rationale: Although specific data processing needs can only be identified through detailed analysis of each application system, it is clear at this time that the trend is toward spacecraft of increasingly greater complexity. A possible outcome of this trend would be to include signal processing in spacecraft which is equivalent to the signal conditioning and switching presently performed in major exchanges of a terrestrial communications network.

The categories shown illustrate the type of signal processing that may be done aboard satellites for communications, data collection, and information network systems. Critical issues in this requirement include development and space qualification of devices and demonstration of applications systems.

5.1.2.4.6.1 Correlation Detectors AC

5.1.2.4.6.2 Channel Filters AC

5.1.2.4.6.3 Data Demodulation AC

5.1.2.4.6.4 Circuit Switch On Command AC

5.1.2.4.6.5 Signal Demultiplexers AC

5.1.2.4.6.6 Signal Multiplexers AC

5.1.2.4.7 Passive RF Components

What characteristics of passive RF components should be emphasized for future development? [25]

---

25. Rationale: Improvements in passive RF components must parallel the development of higher power transmitters and new antennas and the exploitation of new frequency bands. As in other technology areas, specific requirements for any given system may include one or more of the aforementioned characteristics.

5.1.2.4.7.1 High RF Power AC

5.1.2.4.7.2 Low Insertion Loss AC

5.1.2.4.7.3 Temperature Stability AC

5.1.2.4.7.4 Broad Bandwidth AC

5.1.2.4.7.5 Linear Phase Characteristics AC

5.1.2.4.7.6 Other (Requires Definition By Detailed System Analysis) AC

5.1.2.4.8 Primary Power Systems

What development in primary power systems is required for accomplishment of future system requirements?[26]

---

26. Rationale: Although primary power systems are not unique to the communications discipline, since communications has been the first major commercial application of space technology, this discipline is, and will probably continue to be, the primary forcing function on development of space power technology. Accordingly, the aforementioned techniques and problem areas are identified as research objectives.

    Critical issues are the demonstration of system improvements and compatibility with the communications system and antenna structure.

5.1.2.4.8.1 Large Flexible Solar Arrays AC

5.1.2.4.8.2 High Power AC

5.1.2.4.8.3 Heat Dissipation Techniques AC

5.1.2.4.8.4 Construction Techniques For High- Voltage Protection AC

5.1.2.4.8.5 Protection Against Component Failure And Arcing AC

5.1.2.4.8.6 Nuclear Power Systems AC

5.1.2.4.9 New Device Applications

How may future, unfulfilled needs be met by presently unknown devices? AC
Limitations on present devices should be evaluated and future requirements defined as orientation for researchers.

5.1.2.4.10 Low Cost Small User Terminals

What developments are required to reduce quantity production costs for small user terminals?[27]

---

27. Rationale: This research objective is a critical issue for space testing because of: (1) the overall cost of a system in which many small users are to be served by one or a few spacecraft; (2) the required time phasing of flight test demonstration with differing classes of users; and (3) the system design tradeoffs between the space repeater and the user terminals. The aforementioned listing identifies some of the design approaches and components that may contribute to this objective.

5.1.2.4.10.1 Electronically Steered Integrated Circuit Phased Arrays NS

5.1.2.4.10.2 Large-Scale Integration (LSI) Receivers NS

5.1.2.4.10.3 Large-Scale Integration (LSI) Data Modulators NS

5.1.2.4.10.4 Large-Scale Integration (LSI) Data Demodulators NS

5.1.2.4.10.5 Solid State Displays NS

5.1.2.4.10.6 Large Spacecraft Antenna Apertures (See 5.1.2.4.2.1.) NS

5.1.2.4.10.7 High Efficiency Transmitters NS

5.1.2.4.10.8 High Power Space Transmitters (See 5.1.2.4.4.4.) NS

5.1.2.4.11 Input/Output Devices

What improvements in input/output devices are desirable to fulfill requirements of manned space missions?[28]

---

28. Rationale: Although input/output devices are available which at least partially fill known requirements, improvements are desirable in many areas. Since commercial and military

markets also exist for such devices, the space program will probably benefit from technology development in the normal course of events. The aforementioned listing identifies components in which improvements are desirable.

5.1.2.4.11.1 Solid State Video Information Displays AC

5.1.2.4.11.2 Alpha-Numeric Output Display AC

5.1.2.4.11.3 Hard Copy Printer AC

5.1.2.4.11.4 Message Composer AC

5.1.2.4.11.5 TV Cameras AC

5.1.2.4.12 Other Spacecraft Subsystems

5.1.2.4.12.1 Attitude Control AC

What attitude control sensors and systems can meet the 0.01-degree stability requirements of optical communications systems and MM wave systems employing large aperture antennas?

5.1.2.4.12.2 Temperature Control AC

What temperature control devices and techniques are applicable to the loads implied by high power transmission systems?

5.1.2.4.12.3 Power Subsystem (See 5.1.2.4.8.) AC

5.1.2.4.12.4 Power Conditioning AC

What devices and power conditioning systems are required to meet the requirements of high RF power transmission systems?

5.1.2.4.12.5 Station Keeping AC

How may sensors, devices, and control systems be implemented to meet the precision requirements for optical communications and long orbit lifetimes for communications relay satellites?

5.1.2.4.12.6 Bearings AC

How may the reliability of bearings be improved for despun platforms and other applications involving spacecraft parts in relative motion?

5.1.2.4.12.7 Component Service Life AC

Can presently applied quality control and inspection techniques yield the system lifetimes of five to ten years which may be required for manned spaceflight within the solar system? If not, what revolutionary approaches to reliability engineering are implied by this requirement?

5.1.2.4.13 Development To Support Extra-Vehicular Activity (EVA)

What technology developments are required to support EVA for manned space missions?[29]

---

29. Rationale: Although continuing improvements in EVA-related communications equipment will undoubtedly take place, no critical deficiencies in this area are presently known.

5.1.2.4.13.1 Space Suit Transceivers AC

5.1.2.4.13.2 Space Suit Microphones AC

5.1.2.4.13.3 Space Suit Earphones AC

5.1.2.4.13.4 EVA Transceivers For Spacecraft AC

5.1.2.4.13.5 Spacecraft Antennas For EVA Communications AC

5.1.2.4.13.6 Space Suit Communications Antenna AC

5.1.2.4.13.7 Voice Input Mission Recorders AC

5.1.2.4.14 Contributions of Manned Space Flight To Technology Development

How may manned space missions contribute to development of communications technology?[30]

---

30. Rationale: Although other methods of performing deployment and testing are available, the following manned activities may be advantageous because of either (1) system simplicity, or (2) the inability to define, at present, instrumentation requirements for automated performance.

5.1.2.4.14.1 Deployment Of Antennas 5-TF-1

5.1.2.4.14.2 Testing And Calibration Of Antennas 5-TF-1

5.1.2.4.14.3 Repair Through Replacement Of Components 5-TF-2

5.1.2.4.14.4 Inspection For Environmental Effects 5-TF-1,2

5.1.2.4.14.5 Visual Observation Of Flexible Structures 5-TF-1

5.1.2.4.15 Astronaut Safety

What precuations may be required for protection of astronauts?[31]

---

31. Rationale: The advantages of astronaut participation in communications experiments must be weighed against the requirement for incorporation of additional provisions for astronaut safety into the spacecraft design. Such provisions may include one or more of the aforementioned listings.

5.1.2.4.15.1 Interlocks On High Voltage Enclosures AC

5.1.2.4.15.2 High Power Transmitter Turn-Off During EVA AC

5.1.2.4.15.3 Ordnance Expended Or Disarmed Prior To EVA AC

5.1.2.4.15.4 Pressurized High Voltage Enclosures (With Inert Gas) AC

5.1.2.4.16 Demonstration And Test

What space experiments are required by the technology development program?[32]

---

32. Rationale: In a number of the foregoing technology areas, space qualification of components or system demonstration in space were defined as the principal critical issues. For emphasis, a general statement may be made that a comprehensive space test program is desirable to implement the total technology development program. Such a program includes the following classes of demonstrations and tests.

5.1.2.4.16.1 System Simulation

May the conclusions of system concept studies be validated without flight of dedicated satellites? 5-TF-1,2

5.1.2.4.16.2 Subsystem Test In Orbit

Do components and subsystems perform satisfactorily in orbit after passing ground simulation acceptance tests? 5-TF-1,2

5.1.2.4.16.3 Space Qualification of Components

Does the interaction of the space environment with materials result in changes in physical or electrical properties which were not predicted, and which are deleterious to system performance? 5-TF-1,2

5.1.3 RESOURCE MANAGEMENT

5.1.3.1 Frequency Allocation

What is the optimum allocation of the EM spectrum to provide present and future space COMM/NAV services that is compatible with terrestrial and space service requirements?[33]

---

33. Rationale: Frequency allocations may be made on a regional or national basis subject to international agreements and treaties. Studies of (1) national or hemispheric service projections, (2) optimization of the use of the electromagnetic spectrum, and (3) system standards, contribute to establishment of a national position for negotiation. Space experiments may contribute a broad and general information base which contributes to this objective and also assist in popularizing the benefit of applications of space technology. However, the critical issues in this area may be considered (1) consultative, (2) subjects for ground investigation, and (3) political, rather than issues for direct experimental investigation.

5.1.3.1.1 Space-to-Space Links NS

5.1.3.1.2 Space-to-Ground Links NS

5.1.3.1.3 Point-to-Point Telecommunications NS

5.1.3.1.4 TV Services NS

5.1.3.1.5 Data Relay Links NS

5.1.3.1.6 Data Networking NS

5.1.3.1.7 Navigation/Traffic Control NS

5.1.3.1.8 Existing and Planned Terrestrial Systems NS

5.1.3.2 MM Wave Demonstration

5.1.3.2.1 Space-to-Space Links

How does circuit quality of MM wave systems for communications between spacecraft compare to the quality of systems being currently employed for various types of service? 5-CS-1 5-TF-1,2

5.1.3.2.2 Space-to-Ground Links

What limitations are placed on MM wave employment on space-to-ground links by atmospheric absorption and refraction? 5-CS-1 5-TF-1,2

5.1.3.2.3 High Data Rates

Implementation of high data rates in the presently employed bands is limited by both hardware considerations and spectrum crowding. Can MM waves be employed for transmission of data at rates of hundreds of megabits per second? What are the hardware and propagation limits on data rate? 5-CS-1 5-TF-1,2

5.1.3.2.4 Commercial

How may MM waves be employed in the point-to-point services provided by the common carriers?[34] NS

---

34. Discussion: This issue is important to the overall questions of resource management and frequency allocation.

5.1.3.3 Optical Frequency

5.1.3.3.1 Space-to-Space Links

How does circuit quality of optical communications signals transmitted between spacecraft compare to the quality of electromagnetic signals currently used in conventional systems? 5-CS-2 5-TF-1,2

5.1.3.3.2 Space-to-Ground Links

What limitations are placed on employment of optical frequencies on space-to-ground links by atmospheric absorption, refraction, and scintillation? 5-CS-2 5-TF-1,2

5.1.3.3.3 Position Determination

How does the actual performance of optical radars and range determination systems compare to the theoretical performance? 5-CS-2 5-TF-1,2

5.1.3.3.4 High Data Rates

What are the hardware and propagation limitations on the rate at which data can be transmitted at optical frequencies? 5-CS-2 5-TF-1,2

5.1.3.4 Future Needs

What are five- and twenty-year projections of domestic and global requirements for COMM/NAV services?[35]

---

35. Rationale: Requirements forecasting through coordination of future service projections by both government agencies and private industry is an exceedingly important element of resource management and provides inputs both to 5.1.3.1, Frequency Allocation, and to scheduling of development under 5.1.2.4, Technology. Since this critical issue does not lead directly to space experiment requirements, the following listing only suggests the various areas which merit consideration.

5.1.3.4.1 International Traffic NS

5.1.3.4.2 Domestic Traffic NS

5.1.3.4.3 Military Requirements NS

5.1.3.4.4 Future Requirements of Developing Nations NS

5.1.3.4.5 Requirements for Automated Data Handling and Information Retrieval NS

5.1.3.5 Usage and Control

How is the EM spectrum being utilized and how can it be more effectively controlled?[36]

---

36. Rationale: These critical issues (of both national and international importance) are not a primary responsibility of the NASA, and do not lead to new requirements for space experimentation. The role in this overview is to identify possible sources of data developed elsewhere. These data may impact the time span of Earth observations and the schedule for replacement or repetition of NASA experiments.

5.1.3.5.1 RFI Mapping (See 5.1.2.2.1.) NS

5.1.3.5.2 Identification of Radiating Sources (See 5.1.2.2.2.) NS

5.1.3.5.3 Consultation With Regulatory Agencies (FCC, DCA, etc.) NS

5.1.3.5.4 System Standards (Consultation and Development) NS

5.1.3.5.5 Participation In International Management Conferences NS

5.2 NAVIGATION/TRAFFIC CONTROL

5.2.1 SPACE NEEDS

5.2.1.1 Earth Oriented Systems

5.2.1.1.1 Satellite Relay of Range, Range Rate, and Communications Signals Between Earth Stations and Spacecraft

What are the effects of the ground system configuration, and the relay-satellite configuration, on the system accuracy? 5-NS-1 5-TF-1,2

5.2.1.1.2 Data Relay Satellites Between Earth Stations and Mission Control

What are the hardware requirements to satisfy the mission objectives? AC

5.2.1.1.3 Range and Range-Rate Direct Links Between Earth Stations and Spacecraft

What is the effect of the Earth station locations on the navigation accuracy? AC

5.2.1.1.4 Laser Ranging Systems

What are the instrumentation requirements for the space vehicles for the different navigation systems? 5-NS-2 5-TF-1,2

5.2.1.1.5 Ground Data Processing Systems

What are the ground data processing systems requirements for the various navigation systems? NS

5.2.1.2 Autonomous Navigation Systems

5.2.1.2.1 Onboard Radar

What are the practical limits, in radar transmitter power, for example, of the space vehicle radar application? AC

5.2.1.2.2 Radio Direction Finding on Beacon Satellites in Solar Orbit

What position accuracy of the beacon satellites, and of the user, can be achieved? AC

5.2.1.2.3 Observation of Planetary Positions Against Fixed Star Background

Is it feasible to mechanize this technique, and what are the cost and weight estimates? 5-NS-3 5-TF-1,2

5.2.1.2.4 Star Occultations by Nearby Planets and Satellites

Is it feasible to apply this technique under all conditions, or are there any constraints? 5-NS-3 5-TF-1,2

5.2.1.2.5 Handover Between Interplanetary Cruise and Near-Planet Orbits (Change of Navigation Mode)

What are the mechanization requirements for the handover, and what additional instrumentation has to be tested? 5-NS-3 5-TF-1,2

5.2.1.2.6 Stable Inertial Reference Platforms

What are short-term and long-term accuracies, and measured reliability-data, of the inertial components? AC

5.2.1.2.7 Computers for Position Determination, Calculation of Orbits from Successive Fixes, and Coordinate Transformation

What are the computer specifications for the various systems and how may we apply a general-purpose computer? AC

5.2.1.2.8 Sighting and Map Matching of Planetary Features

What is the accuracy of this technique, and what is its dependence on spacecraft position and attitude? AC

5.2.1.2.9 Time References

What is the probability distribution of the time variations of the various signals with reference to a stable clock? AC

5.2.2 AIRCRAFT AND MARINE NEEDS

5.2.2.1 Navigation

How may space systems be employed to determine position referenced to geographical coordinates for presentation to the vehicle operator?[37]

---

37. Rationale: The two basic satellite navigation concepts in the following sections are associated with passive system techniques, and active system techniques. The word "pasive" indicates that the user does not have to transmit or transpond a navigation signal in order to determine his position. An active concept is one in which the user must transmit or transpond a signal in order to determine his position.

5.2.2.1A Passive System Techniques

5.2.2.1.1 Doppler-Only Navigation Through Mutiple Observations of One or More Low-Orbit Satellites

What are the error probabilities of the low-orbit satellites, and how does this affect the overall system accuracy for one or more satellites? 5-NS-1 5-TF-1,2

5.2.2.1.2 Range Difference Navigation Techniques Employing Three or More Satellites and Using Range Signals Controlled By the Same Time Reference

How does the received noise power affect the accuracy of the range difference measurement? 5-NS-1 5-TF-1,2

5.2.2.1.3 Angle Measurement Techniques Employing Two Satellites Containing Transmitting Interferometers and Using Altitude Data

Can the measurements provide the same accuracy as the error analyses indicate as feasible? 5-NS-1 5-TF-1,2

5.2.2.1.4 Angle and Range Measurement Employing a Single Satellite and a Stable Clock

What is the accuracy which can be achieved by this technique, compared to other passive system techniques? 5-NS-1 5-TF-1,2

5.2.2.1.5 Ground Station Support

What are the comparative ground station support requirements of the various possible passive system techniques? NS

5.2.2.1.6 User Equipment

What are the comparative user equipment requirements of the various possible passive system techniques? The characteristic items to be compared are the following:

.1 Cost NS
.2 Power NS
.3 Antenna NS
.4 Computing Facilities NS
.5 Weight and Volume NS
.6 Navigation Accuracy NS
.7 Display NS

5.2.2.1B Active Systems Techniques

5.2.2.1.7 Angle and Range Measurement Employing a Single Satellite and a Transponded Signal By User

What are the system requirements, such as frequency, bandwidth, transmitter power, etc., for implementation of this technique and satisfaction of the accuracy requirements? 5-NS-1 5-TF-1,2

5.2.2.1.8 Range Signals Transponded by User Through Three or More Satellites With User Position Computed at Ground Station

How does the accuracy of this system compare to that of other active systems employing spherical navigation techniques, and what are the cost penalties of the additional satellites? 5-NS-1 5-TF-1,2

5.2.2.1.9 Communications Link to Transmit Data to User

What are the preferred system characteristics, and what are the implementation requirements? AC

5.2.2.1.10 Angle Measurement from Two or More Satellites Using Interferometers With User Position Determined by Ground Station

What are the instrumentation requirements of the satellite and of the ground stations? 5-NS-1 5-TF-1,2

5.2.2.1.11 Ground Station Support

What are the comparative ground station support requirements of the various possible active system techniques? NS

5.2.2.1.12 User Equipment

What are the comparative user equipment requirements of the various possible system techniques? The following characteristic items are to be compared.

.1 Cost NS
.2 Power NS
.3 Antenna NS
.4 Computer Facilities NS
.5 Weight and Volume NS
.6 Navigation Accuracy NS
.7 Display NS

5.2.2.2 Surveillance

5.2.2.2.1 Raw Data (Range) Transmitted from User to Control Center for Independent Fix Computation for Passive Satellite Navigation Systems

What techniques and signal designs are available to satisfy the multiple user requirements and aerial coverage of the system? 5-NS-4 5-TF-1,2

5.2.2.2.2 Position Reporting From User Via Satellite

What are the projected system requirements in connection with the anticipated number of users and frequency of reporting, and what system designs will satisfy these requirements? 5-NS-4 5-TF-1,2

5.2.2.2.3 Air Traffic Control Displays

What message types and contents will be required by the surveillance system, and what data handling and display capabilities will be recommended for the ground control center? NS

5.2.2.2.4 Data Processing Center

What information processing tasks are required for the various functions and phases of surveillance and control (en route command and control, flow control, terminal control, etc.)? NS

5.2.2.2.5 Traffic Control Communications Net

What capacity is required for future communications, and what is the most economic system for this function? NS

5.2.2.2.6 Active Satellite Navigation Systems with All Data Processing and Position Fixing Performed at Surveillance Ground Station

What are the equipment requirements for the ground station? NS

5.2.2.3 Collision Avoidance

5.2.2.3.1 Alarm Communications

What instrumentation is required to provide reliable communications with overriding priority? AC

5.2.2.3.2 Data Processing of Surveillance Data, If All Craft In Area Report To Control Center

How frequencly do position and velocity data have to be reported in order to provide adequate data for collision avoidance? AC

5.2.2.3.3 Beacon Transmissions By All Craft on Same Frequency With Transmission Time Referenced To Received Satellite Clock Signal (Transmissions May Include User Altitude, Course, and Speed Data). 5-NS-5 5-TF-1,2

What is required to integrate a Central Processing System with individual beacon transmissions?

5.2.2.4 En Route Communications

5.2.2.4.1 Passive Navigation Systems in Which Position to Control Center is Reported on Request AC

What signal format reauires the least instrumentation?

5.2.2.4.2 Weather Forecast Service

What are the implementation requirements for integration with candidate passive navigation systems? AC

5.2.2.4.3 Passenger Telephone

What are the future traffic requirements? NS

5.2.2.4.4 Active Navigation Systems in Which Position Fixes are Reported to User on Request

What signal format is required, and what possible user equipment (including display instrumentation) is available? AC

5.2.2.4.5 En Route Weather Reports

What are the implementation requirements for integration with candidate active navigation systems? AC

5.2.2.4.6 Company Communications

What are the traffic and signal format requirements? AC

5.2.2.4.7 Solar Flare Warnings to SST

What are the requirements for the ground stations and the user hardware? NS

5.2.2.4.8 Passenger Entertainment

What future requirements, such as news coverage, can be defined? NS

5.2.2.4.9 Air Traffic Control Circuits

What density is required? NS

5.2.2.5 Search and Rescue

5.2.2.5.1 Angle Determination From Low-Altitude Satellites on Low-Power Emergency Beacon

What are the system characteristics which satisfy the angle determination requirements for low-power beacons, and how can these characteristics be implemented? 5-NS-6 5-TF-1,2

5.2.2.5.2 Observation of Doppler History of Emergency Beacon Signals by Low-Altitude Satellite

What are the equipment requirements for the satellite and the ground control station, to implement this concept? AC

5.2.2.5.3 Traffic Control Systems With Historical File of All Vehicle Positions, Courses, and Speeds in Immediate Area

What capacity is required to file the traffic control data in the various areas, and with what equipment can this be implemented? NS

5.2.2.5.4 Rescue Operations Control and Coordination Communications

Can this function be integrated with the required traffic control communications, and what additional equipment is needed to provide this function? 5-NS-6 5-TF-1,2

5.2.3 SPACE VEHICLE LAUNCH AND REENTRY NEEDS

5.2.3.1 Aerospace Clearances

5.2.3.1.1 Near Term Operations Employing FAA Teletype Circuits Between Mission Control Center and Airport Traffic Centers Originating Flights Through Hazardous Areas

What is the expected traffic loading of these circuits to provide the aerospace clearance data required, and what operational reliability can be achieved with this method? NS

5.2.3.1.2 Future Operations Requiring Central Data Bank Which Stores Flight Data on all Space Operations and Which can be Interrogated by Airport Flight Operations Centers

What equipment is required to provide this capability, and what are the expected equipment costs for the user (airport flight operations), and the control data bank operations? NS

5.2.3.2 Local Traffic Control

5.2.3.2.1 Data Inputs From Mission Control Centers or Direct From Spacecraft

What data on vehicle position, course, and speed are required for control of the local air and marine traffic, and in what signal format can these data be transmitted? AC

5.2.3.2.2 Local Air Traffic Control Centers With Displays and Communications

What is the traffic density for each control center, and what requirements can be defined for the transmission of data from the control center to aircraft and marine users? AC

5.2.3.2.3 Radars

What radar information can be made available to the traffic control centers and to the user crafts, and can the radar functions be integrated with other traffic control and navigation functions? NS

5.2.3.2.4 Navigation System Inputs

What navigation system concept provides the most practical solution to the local traffic control problems? NS

5.2.3.2.5 Near Term Operations Using VHF Communication Nets

What future traffic control functions can be performed by means of VHF communications? AC

5.2.3.2.6 Future Operations Using Satellite Communications Nets (VHF or UHF)

What improvements in traffic control effectiveness and capacity can be provided by the satellite communication nets? AC

5.2.3.3 Corridor Safety

5.2.3.3.1 Local Terrestrial VHF Nets

Can the functions required for corridor safety be performed by existing VHF nets, and if not, what additional system requirements have to be provided? AC

5.2.3.3.2 HF and VHF Guard Channels

What HF and VHF channels are available for space launch and recovery warnings? OP

5.2.3.3.3 U.S. Navy Fleet Broadcast

Can the fleet broadcast system provide the function of corridor safety transmissions to navy traffic? AC

5.2.3.3.4 U.S. Mercast Schedule

Does U.S. Mercast provide the possibility for corridor safety transmissions to merchant shipping? AC

5.2.3.3.5 Foreign Shipping and Rescue Services Using RCA and Other Commercial Communications

Can the safety communications be handled by the services mentioned, and what are the requirements for communications between the space launch and recovery operations and the commercial services? AC

5.2.3.3.6 Future Company Communications Channels for NAVSAT/Traffic Control

How can the company communications functions best be incorporated in future ATC channels for launch and recovery warnings? AC

APPENDIX C

RESEARCH CLUSTER

DESCRIPTIONS

COMMUNICATIONS AND NAVIGATION

INTRODUCTION
APPENDIX C

This Appendix presents the Research Clusters identified by the study team of the Earth Orbital Experiment Program and Requirements Study. Each cluster, in general, consists of (1) a synopsis; followed by (2) a list (by number and title) of the critical issues addressed by the Research Cluster; followed by (3) a crew activity matrix. The identification of these Research Clusters by number and title is given in Table C-1.

Table C-1
RESEARCH CLUSTERS

MANNED SPACEFLIGHT CAPABILITY

Cluster No.	Title
BIOMEDICINE	
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastro-intestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies
BEHAVIORAL RESEARCH	
1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-1-1	Visual Experiment
1-BR-1-2	Behavior Effects of Acoustic Environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive Capability
1-BR-1-5	Orientation
1-BR-2	Group Dynamics and Personal Adjustment

*Missing numbers were assigned to clusters that were later combined with others or eliminated.

Cluster No.	Title
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement

MAN-MACHINE RESEARCH

1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids

LIFE SUPPORT AND PROTECTIVE SYSTEMS

1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair

ENGINEERING EXPERIMENTS

1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)

Cluster No.	Title
1-EE-3-1	Drift Measurement of Gyroscopic Attitude Controls
1-EE-3-2	Disturbance Torque Measurements
1-EE-3-3	Biowaste Electric Propulsion
1-EE-4	Navigation and Guidance (4 parts)
1-EE-4-1	Onboard Laser Ranging
1-EE-4-2	Interplanetary or Translunar Navigation By Spectroscopic Binary Satellite
1-EE-4-3	Landmark Tracker Orbital Navigation
1-EE-4-4	Navigation/Subsystem Candidate Evaluation
1-EE-5	Communications

OPERATIONS EXPERIMENTS

1-OE-1	Logistics and Resupply (2 parts)
1-OE-1-1	Space Logistics and Resupply
1-OE-1-2	Emergency and Rescue Operations
1-OE-2	Maintenance, Repair and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations

SPACE BIOLOGY

VERTEBRATES

2-VB-1	Preliminary Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates

Cluster No.	Title
INVERTEBRATES	
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates
PROTISTS AND TISSUE CULTURES	
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
PLANTS	
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
SPACE ASTRONOMY	
OPTICAL	
3-OW	Optical Structure of Small Extended Sources
3-OB	High-Resolution Planetary Optical Imagery
3-OS	Optical (Faint Threshold) Surveys
3-OP	High Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere

Cluster No.	Title
X-RAY	
3-XR	Precise Location, Size, and Structure of Known Discrete X-ray Sources, and Existence of Additional Unknown Sources
LOW FREQUENCY RADIO	
3-LF	Location and Properties of Discrete LF Radio Sources, and Structure and Properties of Diffuse Sources
SPACE PHYSICS	
PHYSICS AND CHEMISTRY LABORATORY	
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-G
4-P/C-4	Effect of Zero-Gravity on the Production of Controlled Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	The Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero-Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero-G on Liquid Releases, Size Distribution of Liquid Drops
4-P/C-10	Capillary Flow in Zero-G
4-P/C-11	Behavior of Superfluids in the Weightless State
PLASMA PHYSICS LABORATORY	
4-PP-1	Spacecraft-Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)

Cluster No.	Title
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)

COSMIC RAY LABORATORY

4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 MeV
4-CR-9	Nucleon-Nucleon Cross-Sections at High Energies
4-CR-10	Spallation Cross-Sections at High Energies

Cluster No.	Title
COMMUNICATIONS AND NAVIGATION	
NOISE	
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
PROPAGATION	
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
TEST FACILITIES	
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
COMMUNICATIONS SYSTEMS	
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
NAVIGATION SYSTEMS	
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems
5-NS-5	Collision Avoidance System Techniques
5-NS-6	Search and Rescue Systems
EARTH OBSERVATIONS	
EARTH PHYSICS	
6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity

Cluster No.	Title
AGRICULTURE, FOREST, AND RANGE RESOURCES	
6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Crop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping
GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES	
6-G/C-1	Photographic and Multisensor Mapping
GEOLOGY	
6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms
HYDROLOGY AND WATER RESOURCES	
6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins

Cluster No.	Title
OCEANOGRAPHY AND MARINE RESOURCES	
6-O-1	Ocean Pollution Identification, Measurement, and Effects
6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-O-3	Ocean Population Dynamics and Fishery Resources
6-O-4	Ocean Currents and Tide Forecasting
6-O-5	Ocean Physical Properties
6-O-6	Ocean Solid Boundary Processes
6-O-7	Ocean Surface Activity Forecasting
METEOROLOGY	
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas

RESEARCH CLUSTER SYNOPSIS--COMMUNICATIONS

5-N-1 Terrestrial Noise Measurements

1. Research Objectives

The general objective of this research area is to map the apparent noise temperature of the Earth as viewed by a spacecraft-mounted antenna.

Previous experimental work in this area has been performed by radio astronomers measuring extraterrestrial radio sources as viewed from Earth. Some writers have calculated apparent temperatures of the Earth.[1,2] Measurement of the spectral temperature distribution over the Earth's surface, or mapping the ambient signal environment at various regions of the electromagnetic spectrum, is an experiment that could be carried out from a spacecraft laboratory. The resulting data would be of use in such activities as planning and designing satellite and deep-space communications, passive monitoring of electromagnetic activity, meteorological studies, and ionospheric studies. If the Earth were to have a unique electromagnetic signature for various directions, it might serve as an additional navigational check for spacecraft.

2. Background and Current Status

The ambient signal environment is the total RF electromagnetic field energy at a point. In general, the ambient signal environment will have components ranging over the entire radio spectrum. The power spectral density of the energy will be a function of frequency, angle of arrival, and other source parameters such as emissivity. The sources of the ambient signal environment can be broadly classified as follows:

1. Thermal terrestrial.
2. Atmospheric (terrestrial).
3. Extraterrestrial.
    a. Solar.
    b. Planetary/lunar.
    c. Cosmic.
4. Man-made (terrestrial).

In general, the spectra of these components are continuous, with some exceptions (e.g., the atomic hydrogen line at 1.420 GHz) and with some man-made contributions. A spacecraft antenna viewing the Earth will have incident upon it components from all of the above sources. Terrestrial and atmospheric components will be attenuated by the atmosphere, as a function of source location and frequency. Extraterrestrial components will arrive by way of reflection from the atmosphere, the Earth, or both. The spectra will be affected by the absorption and reflectivity of both and will also exhibit frequency and direction of arrival dependence. Direct illumination by extraterrestrial sources will also be present, but their contributions will depend very heavily upon the side and backlobe structure of the radiation pattern of the antenna in question and upon the extent of illumination of the main beam beyond the terrestrial intercepts (edge of Earth coverage).

Man-made sources of RF will be of two general types:

1. Discrete spectral outputs of transmitters.

2. Distributed spectral outputs of random generators, such as machinery.

The geographical distribution of these sources will tend to be localized in areas of high population density and industrial activity. The temperature of many of the discrete sources will tend to be quite high in comparison with the thermal background (in bands where atmospheric absorption is not excessive). As an example, Pawsey and Bracewell[3] state that in a 1-Hz bandwidth at 100 MHz, the radiation from the entire sun is about 20 w. This is equivalent to the output of a 120-kw transmitter with a 6-kHz bandwidth at 100 MHz.

Pawsey and Bracewell give a convenient tabulation of the effects of the atmosphere upon radio-frequency propagation in various portions of the spectrum.[3] Chen and Peake have calculated the apparent surface temperatures for smooth and rough terrain at different frequencies (principally between 1 and 75 GHz) for altitudes of 2 km and 32 km, vertical and horizontal polarization, and various look angles.[1] Thermal noise temperatures and absorption by the atmosphere were computed for six wavelengths in the microwave region between 0.43 and 3 cm by Weger,[2] assuming a 10-km upper limit for the atmosphere and a plane Earth, as a function of look angle.

3. Description of Research

In measuring the terrestrial noise temperature from a spacecraft, the basic observables are the antenna temperature, the antenna pointing angles, the orbit position, and the frequency band to which the receiver is tuned. The research can best be described as that of mapping the Earth with a wide-bandwidth radiometric receiver (an antenna-receiver combination that produces an output signal proportional to the temperature of the object within the antenna pattern).

For frequencies in the 0.1- to 100-GHz portion of the electromagnetic spectrum, the power received from an object that fills the antenna beam is

$$P = kT\Delta f$$

where
- k = Boltzmann's constant
- T = apparent source temperature
- Δf = receiver predetection bandwidth

If the radiometer detects a change in the power received, this change can be interpreted as a change in the source temperature in accordance with

$$\Delta T = \frac{\Delta P}{k\Delta f}$$

The predetection bandwidth Δf is a characteristic of the receiving system, which may be adjusted to suit particular conditions of the experiment. As can be seen from the above relationship, the resolvable temperature difference between antenna spatial resolution elements is inversely proportional to Δf. For a Dicke type radiometer, the resolvable temperature difference between an instantaneous spatial resolution element and a reference internal to the receiver is proportional to

$$\Delta T \propto \sqrt{\frac{1}{\Delta f}}$$

The primary measurement is antenna temperature, and for noise sources at thermal equilibrium, several special cases must be distinguished. For the Earth's solid surface, the polarization of the emitted and reflected radiation will vary with viewing angle. Water surfaces will also exhibit this effect, but in addition, they will behave more strongly as reflectors, in the 0.1- 100-GHz region, than as emitters. The Earth's atmospheric emission will also depend on the thickness encompassed within the antenna beam and strongly upon the frequency. Weather patterns will affect these noise measurements.

The frequencies used should be the ranges corresponding to present and foreseen Communications/Navigation system usage:

136 MHz to 150 MHz
300 MHz
1700 MHz to 1800 MHz
2250 MHz to 2300 MHz
3700 MHz to 4200 MHz
5925 MHz to 8400 MHz
16 GHz
32 GHz

Bandwidths of about 100 MHz should be used in the 1-GHz and higher-frequency region. Such values can provide ΔT resolution of 1° K within a considerable range of orbit and other system parameters.

Noise measurements should be made at about 3-hour intervals, at least over locations that are likely to be covered by Communications/Navigation satellite systems. Such measurements extending at least over a calendar year would be desirable.

The equipment required consists of antennas and receivers operating in the regions of the Communications/Navigation Satellite frequencies. The data consist of a signal that represents the antenna temperature of the instantaneous resolution element, averaged over the antenna beam's footprint within the receiver bandwidth. These data must be recorded and related directly to the pointing angle and geographical location so that contours of given levels of noise power can be constructed.

Some frequency regions will receive contributions to the antenna temperature through the secondary lobes of the antennas. These contributions are those resulting from emission from solar, lunar, and galactic sources. The latter category includes the radiation due to interstellar atomic-hydrogen at 1420 MHz. This suggests that some experiments be performed with an antenna in the opposite direction from that viewing the Earth so that perhaps these contributions can be distinguished.

A large-diameter space-erectable antenna with changeable broadband feeds would be a useful adjunct to this experiment.

4. Impact on Spacecraft

The spacecraft orbit inclination should be 90 degrees to provide full global coverage. Orbit altitude should be between 200 and 1000 nmi, as a compromise between acceptable drag and antenna structure size. Ground resolution is a function of antenna aperture. Spacecraft attitude stability should be within 0.5 degree, and the attitude determination system should provide about ±1 degree pointing accuracy of the antennas. Orbit determination should provide a ground location accuracy of ±1 nmi.

The role of man in this experiment will consist of configuring the spacecraft receivers and monitoring the data outputs. As the experiment proceeds, it may become necessary to make certain changes; for example, in postdetection integration time constants, and in temperature of the radiometer calibration source. The use of a large, space-erectable antenna would require astronaut extravehicular activity and special training.

5. Required Supporting Technology Development

A major technological area that requires further development is that of signal processing, data sorting, and hard-copy production, specifically for signal mapping. Another fundamental problem is that of maintaining, or at least compensating for, the variation in resolution over the necessarily broad frequency spectrum covered in the experiment.

6. References

1. S.N.C. Chen. and W. H. Peake. Apparent Temperatures of Smooth and Rough Terrain. IRE Transactions on Antenna Wave Propagation, November 1961, pp. 567-572.

2. E. Weger. Apparent Thermal Noise Temperature in the Microwave Region. IRE Transactions on Antenna Wave Propagation, March 1960, pp. 213-217.

3. J. L. Pawsey and R. N. Bracewell. Radio Astronomy. Oxford University Press, Oxford, England, 1955.

7. Bibliography

Aerial RF Noise Measurement in Urban Areas at UHF Frequencies. AIAA Paper No. 70-437, AIAA Third Communication Satellite Systems Conference, Los Angeles, California, April 6-8, 1970.

Feasibility Study of Man-Made Radio Frequency Radiation Measurements from a 200-Mile Orbit. General Dynamics Report No. ZZK68-007, Contract NASW-1437, February 15, 1968.

Harris, D. B. Microwave Radiometry. Microwave Journal, May 1960.

Hoffman, L. A., K. H. Hurlbut, and C. J. Zamites, Sr. Radio Frequency Interference at Orbital Altitudes. IEEE Transactions on EMC, EMC-8, March 1966, pp. 1-7.

Straiton, A. W., C. W. Tolbert, and C. O. Britt. Apparent Temperature Distribution of Some Terrestrial Materials and the Sun at 4.5-mm Wavelength. Journal of Applied Physics, Vol. 29, May 1958, pp. 776-782.

Hogg, D. C. Effective Antenna Temperature due to Oxygen and Water Vapor in the Atmosphere. Journal of Applied Physics, Vol. 30, September 1959, pp. 1417-1419.

Critical Issues Addressed by Research Cluster

5-N-1

TERRESTRIAL NOISE MEASUREMENTS

5.1.2.2.1.1
How does the output noise power of Earth-illuminating receiving antennas depend upon the center of the received frequency band?

5.1.2.2.1.2
How does the output noise power of Earth-illuminating receiving antennas depend upon the geographic coordinates of the area viewed by the antenna?

5.1.2.2.1.3
How does the output noise power of Earth-illuminating receiving antennas depend upon local time at the area viewed by the receiving antenna?

5.1.2.2.1.4
What is the short term distribution of noise voltage relative to the root-mean-square noise power at the output of Earth-illuminating receiving antennas?

RESEARCH CLUSTER NO. 5-[illegible]-1

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.		TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CO[illegible] †
5-N-1	C1	Install and Erect Antenna and Feeds (EVA)	Antennas and Transmission Lines	3			21-A	As required	150	1-2	'74	1 yr	See 5-II-1
	C4	Connect pre-selector to antenna and multiplex filter	Channel Control Console	2			17-A		10 per antenna patch	1	"	"	
	C2	Calibrate 20 Radiometers and associated antenna. Record VSWR.	Std. Noise Source VSWR Test Set Noise Spectrum Display & Recorder	3			17-A		60 per receiver	1-2	"	"	
	C3	Select frequency band to be monitored from pre-assigned sequence.	Channel Control Console	2			17-A		20	1	"	"	
	C5	Start automated data collection program	Channel Control Console	2			17-A		5	1	"	"	
	C6	Review data on quick look display	Noise Spectrum Display	2			17-A	At 2-Hr. Intervals	30	1	"	"	
	C7	Where data is inconsistent employ panoramic adapter on monitor channel at output of multiplex filter at next target opportunity (calibration site).	Signal Display Console	2			17-A	As required	60-120	1	"	"	
	C8	Initiate computer to prepare plots of 5 db contours (global maps).	Computer Key-board CRT	4			17-A		10		"	"	
	C9	Manually steer antenna for Point Observations.	Antenna Control	2			17-B		10-20	1	"	"	
	C10	Stabilize Spacecraft	S/C Controls	5			21-A		Undetermined.	1	"	"	
	C11	Start Recorders	Recorder Controls	4			17-B			1	"	"	
	C12	Observe Meteorological Data in Area under Investigation (Clouds, Storms)	Window Optical Aids(?)	2			21-A		5-10	1	"	"	
	C13	Check noise meter or printout for approximate validity of current measurement.	Noise Spectrum Display	4			17-A		10	1	"	"	C-16
	C14	Check Computer Printout for summary of measurements	Computer	4			17-A			1	"	"	C-8
	C15	Set attenuators to establish range of data	Channel Control Console	2			17-B		10-20	1	"	"	C-6
	C16	Compare data on passes over same area (if different, repeat observations).		4			17-A		30	1	"	"	

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

~~C-5-7~~

LEGEND OF CODES USED IN, TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS--COMMUNICATIONS

5-N-2 Noise Source Identification

1. Research Objectives

The objectives of this research area are to geographically locate and identify terrestrial sources of electromagnetic radiation in the 0.1- to 100-GHz portion of the spectrum. Electronic oscillators and other noise generators that cannot be categorized by thermal equilibrium comprise the sources to be located and identified.

Accomplishment of the objectives is envisioned through the use of broad-bandwidth antennas, scanning receivers, and signal-processing equipment aboard a manned spacecraft. With this equipment and man's participation, the terrestrial signal environment signature may be collected and analyzed to determine interfering levels and associated modulation structures.

The knowledge gained by pursuing this research will permit more-efficient use of the spectrum, aid in establishing frequency allocations and system standards, and place the United States in an informed position regarding negotiations for international frequency allocations.

2. Background and Current Status

In general, the noise sources to be located and identified are man-made, specifically the spectrally discrete outputs of RF transmitters and the distributed spectra of such random generators as machinery. Being man-made, the geographical distribution of these noise sources tends to be concentrated in areas of high population density and industrial activity.

A considerable amount of equipment has been developed, especially for S- and X-band military missions, specifically for identifying the classes of known transmitters (commercial and industrial broadcasting stations, radars, and certain varieties of industrial equipment). This equipment can generally be categorized as being in the spectrum analysis class.

3. Description of Research

Noise sources may be located and identified by obtaining the signature of the emitter and its geographical coordinates. This is accomplished through the use of narrow-beam, broad-bandwidth antennas, panoramic receivers, and appropriate signal-processing equipment.

Requirements may be established from the relationship of signal-to-noise ratio (S/N), antenna beamwidth ($\Delta\Omega$), and dwell time (τ) of the antenna beam at a given position on the Earth. This last parameter depends upon spacecraft orbit characteristics. These three quantities form a triple product, which has a constant value as follows:

$$S/N \cdot \Delta\Omega \cdot \tau = \text{constant}$$

If the antenna beam is made very narrow, giving great precision in emitter location, the dwell time also decreases, making it necessary for the signal level of the emitter to be large; that is, under such circumstances weak emitters will be identified with uncertainty. To make this model slightly more realistic, the additional variable (carrier frequency) can be added. This is equivalent to dividing the dwell time per spatial resolution element into intervals within which a frequency search must also be carried out. Other such variables can also be added.

Mapping of RF emitters located on the Earth in the frequency range of extremely low frequency through extremely high frequency is an ambitious program. The objective of the mapping experiment is to measure the received RF energy level and perhaps polarization over the spectrum versus Earth latitude and longitude at some convenient orbital altitude. To accomplish the experiment efficiently, the spectrum could be divided into bands, each suitable for implementing an antenna and a swept receiver. As an example, the standard frequency bands shown in Table 1 might be appropriate.

Since the equipment required to perform this research is similar to that required for 5-N-1 Terrestrial Noise Measurements, the two groups could, conceivably, be performed sequentially.

Table 1: STANDARD FREQUENCY BANDS

Frequency Range	Band Designation
0.3 to 3 kHz	ELF
3 to 30 kHz	VLF
30 to 300 kHz	LF
0.3 to 3 MHz	MF
3 to 30 MHz	HF
30 to 300 MHz	VHF
0.3 to 3 GHz	UHF
3 to 30 GHz	SHF
30 to 300 GHz	EHF

4. Impact on Spacecraft

The spacecraft's orbit inclination should be 90 degrees to provide global coverage. Orbit altitude should be between 200 and 1000 nmi as a compromise between acceptable drag and antenna structure size. Ground resolution is a function of antenna aperture. Spacecraft attitude stability should be within 0.1 degree, and the attitude determination system should provide ±10-arc-sec pointing accuracy of the antennas. Orbit determination should provide ±1 nmi ground-location accuracy.

The role of man in this experiment will consist of configuring the spacecraft receivers and monitoring the data outputs. As the experiment proceeds, it may become necessary to make certain changes; for example, in postdetection integration time constants, and in temperature of the radiometer calibration source. The use of a large space-erectable antenna would require extravehicular activity and special training.

Since similar equipment and identical coverage is required for 5-N-1 Terrestrial Noise Measurements, the two groups should share the same spacecraft facility.

5. Required Supporting Technology Development

To perform the experiment efficiently; i.e., to maximize the spectrum width observed per unit time, special receivers and antennas with high-speed switching of frequency bands is required.

A major technological area that requires further development is that of signal processing, data sorting, and hard-copy production, specifically for signal mapping. Another fundamental problem is that of maintaining or at least compensating for the variation in resolution over the necessarily broad frequency spectrum covered in the experiment.

6. References

1. Aerial RF Noise Measurement in Urban Areas at UHF Frequencies. AIAA Paper No. 70-437, AIAA Third Communication Satellite Systems Conference, Los Angeles, California, April 6-8, 1970.

2. Feasibility Study of Man-Made Radio Frequency Radiation Measurements from a 200-Mile Orbit. General Dynamics Report No. ZZK68-007, Contract NASW-1437, February 15, 1968.

3. S.W. Fordyce. A Radio-Frequency Spectrum Analysis Experiment for the Manned Space Station Program. Memorandum, May 7, 1970.

4. D. B. Harris. Microwave Radiometry. Microwave Journal, May 1960.

5. L. A. Hoffman, K.H. Hurlbut, and C.J. Zamites, Sr. Radio Frequency Interference at Orbital Altitudes, IEEE Transactions on EMC, EMC-8, March 1966, pp. 1-8.

Critical Issues Addressed by Research Cluster

5-N-2

NOISE SOURCE IDENTIFICATION

5.1.2.2.1.1
How does the output noise power of Earth-illuminating receiving antennas depend upon the center of the received frequency band?

5.1.2.2.1.2
How does the output noise power of Earth-illuminating receiving antennas depend upon the geographic coordinates of the area viewed by the antenna?

5.1.2.2.1.3
How does the output noise power of Earth-illuminating receiving antennas depend upon local time at the area viewed by the receiving antenna?

5.1.2.2.1.4
What is the short term distribution of noise voltage relative to the root-mean-square noise power at the output of Earth-illuminating receiving antennas?

5.1.2.2.2.3
How can aural or visual monitoring of received interfering signals significantly contribute to identification of man-made noise sources?

5.1.2.2.2.4
How can RDF techniques contribute significantly to identification of interfering man-made noise sources?

5.1.2.3.4.7
Can the results of the computations suggested in 5.1.2.3.4.6 be used in the prediction of actual observations for space? (See research objective 5.1.2.2.1.)

C-?

RESEARCH CLUSTER NO. ~~5-N-2~~

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-N-2 -1	Select frequency band of interest (0.1 to 100 GHz)		3			17-A	As required	20	1	'74	1 yr.	See 5-N-1
-2	Connect receiver equipment in appropriate configuration (EVA) for noise measurements.		3			17-A	As required	30-150	1-2	"	"	
-3	Perform calibration test and start tape recorder.		3			17-A	Once/run	60 per receiver	2	"	"	
-4	Monitor panoramic display for adequate sensitivity or saturation		5			17-A	Each target per 16 orbits	6	1	"	"	
-5	Compare frequency spectrum with previous data		6			17-A	Once/run	10-20	1	"	"	
-6	Maintain tape records of modifications in experimental setup		5			17-A	continuous	—	1	"	"	
-7	Monitor panoramic display of frequency spectrum in real time.		5			17-A	Once per orbit	30	1	"	"	
-8	Adjust signal attenuators as required to prevent saturation		5			17-A	1-2 times per run	30	1	"	"	
-9	Steer or adjust antennas as req'd		5			17-A	As required	30-60	1	"	"	
-10	Evaluate whether a valid experiment pass was taken and note whether signal levels were above threshhold values.		6			17-A	As required	30	1	"	"	-4, -5
-11	Record signal levels from active emitters with CM wavelengths and smaller as required.		8			17-A	As required	10	1	"	"	

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—COMMUNICATIONS

5-P-1 Ionospheric Propagation Measurements

1. Research Objectives

Briefly stated, the general objective of this research area is to investigate the RF transmission properties and structure of the ionosphere for the purpose of developing more precise ionospheric predictions. These properties include the spatial and temporal distributions of electron density, which in turn affect attenuation, refraction, coherent bandwidth, and polarization rotation of electromagnetic waves propagating through the medium.

The knowledge gained by pursuing these research objectives will benefit future space communication and navigation systems by making the use of the electromagnetic spectrum more efficient, by increasing the predictability of transmission links, and by reducing propagation errors affecting both tracking and navigation systems.

2. Background and Current Status

The ionosphere is that region of the Earth's atmosphere in which the constituent gases are ionized by radiation from outer space (chiefly solar radiation). This region extends from about 50 to 1000 km in height, with the maximum ionization density occuring at about 300 Km. An abundance of free electrons causes a significant conductivity and consequent modification of the radio-frequency refractive index.

During the day, the bulk of the ionization is at altitudes between 90 and 1000 km, where the electron density is approximately 10^4 electrons per cc. Throughout the ionosphere, there are in fact, several layers or regions in which the ionization density either reaches a maximum or remains roughly constant. These regions are designated D, E, and F in order of height. During the daytime the F layer splits into separate layers called F_1 and F_2. Also at times, a peak in electron density has been observed in the lower D region, suggesting that the designation of C region might be appropriate for the 50- to 70-km range. The actual electron-density distribution is a function of many variables, including time of day, season, latitude, and year (in relation to the 11-year sunspot cycle).

The ionosphere has a pronounced effect on radio waves, and this effect is a function of the electron density. Earth-space propagation parameters affected include phase-path length change, refraction, frequency change, group-path delay, polarization rotation, and absorption.

The point refractive index is a function of the local free-electron density and is <u>less</u> than unity, which implies that the phase velocity in the ionosphere is greater than that in free space. Thus, a carrier phase measuring system, prior to correction, for example, will indicate a range smaller than actual. Conversely however, it is easily shown that the group velocity is less than that in free space by the same amount that the phase velocity is greater, so that group or modulation delay measurements indicate a range greater than actual.

As mentioned earlier, the ionosphere is highly variable as a function of time of day, season of year, time in the sunspot cycle and geographic position. The result is that the total electron content may be expected to vary over somewhat more than an order of magnitude under conditions of interest to navigation satellites.

The above clearly indicates that a standard correction is of little value for the ionosphere. Errors of 100 percent or more, relative to the average, could be expected. Measurements of the total electron content are possible either by two-frequency or Faraday rotation sensing. Neither of these, however, appears practical for real-time navigation satellite applications.

Lacking real-time measurements, the best that can be done is to predict the electron content as a function of time and place. Fortunately, a practical and reasonably effective means is available for doing this. This correction is based on the data provided monthly by ESSA.[1] These data provide predictions 3-months in advance, including among other things:

f_oF2	the maximum frequency reflected from the ionosphere at vertical incidence, a measure of the maximum ionization density
MUF(4000)F2	the 4000 km maximum usable frequency, an indirect measure of vertical scale of the ionosphere.

By a combination of theoretical modeling and regression analysis against actual electron content measurements, a semi-emperical prediction equation for the total ionospheric columnar electron content has been developed.[2]

By actual comparison against 292 Faraday rotation measurements at Penn State, the standard error of prediction of this formula has been found to be 25 percent of the quantity predicted, which is probably about as well as can be done, with on-the-spot measurements.

Because of the height of the ionosphere above the Earth, the elevation angle within the ionosphere is considerably greater than that at the ground; consequently, an obliquity factor has been developed. By comparison with actual ray-tracing calculations, it has been found that use of the obliquity factor gives an adequate fit to the variation with elevation angle.

It has been found that although the predictability of the ionospheric error is rather poor (25 percent by the above model), the residual errors tend to be highly correlated over distances that are significant in satellite navigation. This fact has important consequences, since there will be a strong tendency for the ionospheric errors generated by range differences to various satellites to cancel. This is true particularly if one is concerned with relative navigation errors between two user aircraft.

The total system bandwidth of a satellite communication system is limited not only by equipment factors in the transmitter, the spaceborne transponder, and the receiver, but also by the dispersive nature of the ionosphere.

The presence of electrons in the ionosphere introduces attenuation and phase distortion in the propagation of radio waves. These effects are complex functions of the frequency. Neglecting secondary effects from the geomagnetic field, the attenuation constant in an isotropic ionosphere layer is a function of the electron density, the collision frequency of the electrons, and the transmitted wavelength. This expression for the ionospheric attenuation constant is adequate at microwave frequencies when the refraction index in the ionosphere is sufficiently close to unity.

The bandwidth, which can be sustained by the ionosphere, can be estimated if we assume that the attenuation difference between the transmitted frequency components should be no greater than 1 dB (1/8.686 = 0.1151 Neper). Using this as a criterion and a carrier frequency of 4 GHz, the resulting bandwidth is 3.3 GHz. It is therefore apparent that the variation of the attenuation constant with the frequency will not result in a significant constraint upon the RF bandwidth in the microwave region. It remains to be determined whether the variation of the phase constant with frequency is significant.

The expression, the localized refractive index, is valid when the frequency f is much greater than, first, the gyromagnetic frequency ($\approx$ 1.4 Mhz), and second, the collision frequency between electrons and ions or molecules. Both of these conditions are satisfactorily fulfilled in the ionosphere for operating frequencies in the microwave region.

The total integrated electron density has been obtained by measuring the Faraday rotation on moon-echo experiments, and a nominal maximum value for normal solar activity has been found to be 2×10^{17} per m^2 for vertical paths.

This is not substantially different from the value obtained by assuming the value $N = 10^{12}$ (F_2 region) and a total height of 400 km for the ionosphere $10^{12} \times 400 \times 10^3 = 4 \times 10^{17}$). For a frequency of 4.0 GHz, therefore, we have

$$\Delta f = 97 \text{ MHz}$$

which corresponds to a bandwidth of 194 MHz. It is concluded, therefore, that for most bandwidths of concern today in the microwave region, the ionosphere has practically no limiting effects, except perhaps for very high phase-modulation rates, which are characteristic of sophisticated countermeasures.

3. Description of Research

Many properties of the ionosphere are inaccessible to terrestrial measurement because of the extreme spatial and temporal variability. Measurements of the distribution of electron density in the ionosphere will be made by the use of ionospheric sounding (ionosounders) located in the spacecraft. Ionospheric sounding allows time resolution and continuity—the sensitivity and dynamic range required of an effective method of measurement. This involves the transmission of an RF pulse (at the frequency at which the ionosphere's characteristics are desired) and the measurement of the received backscattered signal strength.

The methodology consists of processing the received backscattered signals, which are a function of space (antenna arrays and pointing angles), time (time of transmission from the spacecraft), and frequency (frequency of the transmitted signal). The processing could assume that the received signal obeyed the wave equation

$$\nabla^2 \mu[t, x, y, z] = \frac{1}{(C')^2} \frac{\partial^2 \mu}{\partial t^2}$$

where

$C' = C(Z)$, Z = altitude

C = velocity of propagation

An extension of normal top-side sounding methods will involve the use of subsatellites to sense the sounder signal and to perform localized soundings in an attempt to obtain three-dimensional, nearly simultaneous profiles. One or more subsatellites may be put in various orbits for relaying the ionograms. The sounding experimental methodology will involve transmission of a radio pulse at various desired, closely spaced frequencies into the ionosphere and recording until the desired range of frequencies is covered. Further detail on local electron density and horizontal structure is obtained by receiving the sounder signals at the subsatellite.

High-frequency signals (< 100 MHz) from a satellite transmitted through the ionosphere may suffer amplitude and phase distortion, thus restricting the coherent bandwidth. This distortion is caused by variation in electron density, normal to the transmitted wavefront. To measure the amplitude and phase variations of the signal, an amplitude modulated signal transmitted from one of the subsatellites may be used. Several modulation frequencies used to either simultaneously or sequentially modulate a carrier will produce sidebands removed from the carrier by the modulating frequency. If these modulating frequencies are so synthesized from the carrier that they retain their phase relationship, both the relative amplitude and the phase differences over the band may be measured. The experiment should be performed at various frequencies below 100 MHz and over long time periods to determine hourly, diurnal, and seasonal variations.

4. Impact on Spacecraft

The altitude extent of the ionosphere (50 to 1000 km) suggests that a low-orbit spacecraft, such as the Space Station or experiment modules, be used as the platform for this research cluster. In fact the remote maneuverable subsatellite (RMS) defined in the "Blue Book" (Reference 4) is ideally suited for the role of the subsatellite in this experiment.

Steerable antennas would be required on the spacecraft, but the pointing accuracy would not be stringent (perhaps 1 degree). Station keeping is not critical, but the spacecraft orbital position at the time of measurement is important for correlating with other observables. Attitude control is necessary only as far as it affects antenna pointing.

The role of man in conducting the experiment is important. He will set up and operate the equipment, review and correlate results, and perhaps help in data reduction and onboard processing. The test instruments may remain essentially unattended in transponding mode, with the exception of monitoring such items as visual metering and displays.

5. Required Supporting Technology Development

Maximum use will be made of current research and technology programs such as ISIS-1, ISIS-B and -C, and Alouette. Experiments will complement these activities during on going programs, and as a result, no new supporting research and technology may be required.

6. References

1. Ionospheric Predictions. U.S. Department of Commerce, ESSA.

2. J. J. Freeman. Final Report on Ionospheric Correction to Tracking Parameters. NAS5-9782, November 3, 1965.

3. Afraymovich. Determination of Ionosphere Plasma Density from Phase-Frequency Characteristics. Geomagnetism and Aeronomy, Vol. VIII, No. 4, p. 518.

4. Candidate Experiment Program for Manned Space Stations. NHB 7150.xx, September 15, 1969.

7. Bibliography

Lawrence, et al. A Survey of Ionospheric Effects Upon Earth-Space Radio Propagation. Proceedings of the IEEE, January 1964.

Special Issue on Top-Side Sounding and the Ionosphere. Proceedings of the IEEE, June 1969.

Mallinckrodt, A. J. Distribution Function for Ionospheric Errors. TRW IOC 7222.2-419, February 23, 1968.

Chen, C. C. Range Difference Error due to the Presence of Ionospheric Electrons. Proceedings of the ITC Conference, IEEE, Boulder, Colorado, June 9, 1969.

Mallinckrodt, A. J. Propagation Errors. Notes for UCLA Short Course, October 13-24, 1969.

Ross, W. J. The Determination of Ionospheric Electron Content from Satellite Doppler Measurements. Journal of Geophysical Research, Vol. 65, 1960, pp. 2601-06.

Nisbet, J. S. Electron-Density Distribution in the Upper Ionosphere from Rocket Measurements. Journal of Geophysical Research, Vol. 65, 1960, pp. 2597-99.

Critical Issues Addressed by Research Cluster

5-P-1

IONOSPHERIC PROPAGATION MEASUREMENTS

5.1.2.3.1.1
How does signal strength from a satellite in synchronous orbit depend upon ground station location and ionospheric conditions as determined by conventional ionospheric sounders as a function of frequency? (This is of increasing importance as frequency decreases below VHF.)

5.1.2.3.1.2
How does the apparent angle of arrival of signals propagated through the ionosphere vary as a function of time and frequency? Can the statistics be predicted from ionospheric sounder or solar wind date?

5.1.2.3.1.3
After passage of a signal through the ionosphere, what is the probability distribution of the polarization vector of the signal from a linearly polarized transmitting antenna? Can the statistics be predicted or correlated with ionospheric sounder or solar wind data?

5.1.2.3.1.4
The interaction of two signals passing through an ionized medium in a magnetic field produces sum and difference frequency signals. What is the magnitude of the mixed components and what is the contribution of this effect to the ambient noise?

5.1.2.3.1.5
At frequencies that are significantly influenced by the ionosphere how do the statistics of signals observed as described above vary with local time and within geomagnetic latitude and longitude differences between a satellite and an Earth terminal?

5.1.2.3.1.6
Many observed phenomena are currently explained by ascription of a time and spacial density structure to the ionosphere, resulting in signal components received over multiple paths at slightly varying times. What is the distribution in the arrival time about the nominal time of pulse signals when referred to a stable clock?

5.1.2.3.1.7
A time-varying ionospheric structure as described in 1.2.3.1.6 will contribute a measurable spreading of a signal in the frequency domain. What is the distribution of phase noise in a signal derived from a stable oscillator?

5.1.2.3.1.8

The classical model of HF skywave propagation treats the ionosphere as stratified layers of differing index of refraction, with structure when necessary to explain certain observed phenomena. What is the ratio of signal strength reflected in various skywaves to the signal strength transmitted completely through the ionosphere and how do the reflection coefficients depend on frequency?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 5-P-1

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY +	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL +	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START +	DURATION +	TASK CONCURRENCY +
5-P-1 -1	Connect and Check out antenna and Feed System		3			21 B		150	1-2			
-2	Connect and Turn on Ionosounder, receivers, and recorders and calibrate set-up.		5			17 B		60 Per Receiver	2			
-3	Activate equipment for monitoring various voltages and currents		5			17 B		20.30	1			
-4	Monitor antenna loading versus frequency		5			17 B		30	1			
-5	Deploy subsatellite		5			21 B	Once Per Mission	120-140	2			
-6	Monitor data recording equipment		5			17 B	Once/Run	10	1			
-7	Observe meteorological phenomena of the area under investigation		7			12 B		5-10	1			
-8	Examine the graphically recorded data at periodic intervals		6			17 B		10-30	1			
-9	Adjust bandwidths, power and antenna loading, repeat steps 3 through 8 as required		5			17 B	As Req.	30	1-2			

+See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—COMMUNICATIONS

5-P-2 Tropospheric Propagation Measurements

1. Research Objectives

The objective of this research group is to measure the effects of the troposphere on RF propagation parameters, specifically the effects of water vapor and molecular oxygen content upon attenuation, phase, and refraction as a function of frequency. Since the constituents of the troposphere are spatially and temporally distributed random variables, the experiment becomes one of determining the statistics of propagation along various parameters, such as path lengths, elevation angles, time of year, season, climate, and weather conditions.

By meeting these objectives, the electromagnetic spectrum may be used more efficiently, transmission links may become more reliable and predictable, and tracking and navigation systems may be improved through the reduction of propagation errors.

2. Background and Current Status

Before RF transmission systems that call for use of certain frequencies in the Earth's atmosphere can be designed, statistical data must be available. For example, predictions are required on the percentage of the time when attenuation for a given frequency range exceeds 10, 20, or 30 db. Such data must be known for a variety of locations, weather conditions, and satellite-to-ground terminal geometries.

The effects of the earth's atmosphere on the propagation of both electromagnetic and optical waves have been investigated in theory and in experiments by many investigators. The one observation that seems common to all of the studies is the non-deterministic nature of the processes that contribute to the phenomenon, since there are virtually an infinity of possible atmospheric conditions, each of which can be described only in a statistical manner with reference to its effects on propagations at both microwave and optical frequencies. To help overcome this seemingly intractable analytical problem, the effects may be described in terms of three basic functions: attenuation, refraction, and atmospheric noise.

Attenuation of electromagnetic waves atmosphere is normally caused by two mechanisms:

1. Energy is absorbed and converted to heat.

2. Energy is scattered out of beam.

Moisture from both clouds and precipitation, whether in liquid or solid form, are the major constituents which contribute to the attenuation of waves passing through atmosphere. Equations for computing both absorption and scatterings have been derived and carried out by Ryde and Ryde, [1] based on Mie's theory. Generally, the attenuation caused by rain increases very rapidly with increases in drop size in both millimeter and centimeter wave regions. Experimental observation also indicates that there is reasonably good correlation between raindrop size and rainfall rate, and that drop size increases with rainfall rate. Typical drops vary from 1 to 6 mm in diameter. If the wavelength is appreciably greater than the drop size, the attenuation is caused almost entirely by absorption.

It has also been found that attenuation resulting from rain is approximately proportional to the number of droplets per unit volume. For rigorous calculations, however, it is necessary to specify the drop size distribution and the rainfall rate.

In passing from one medium to another, the electromagnetic wave will experience refraction due to a change in the velocity of propagation. The index of refraction of the Earth's atmosphere is independent of frequency in the region of millimeter and centimeter waves, but it is directly related to such atmosphere variables as temperature, atmospheric pressure, and water-vapor pressure. The practical model of troposphere that is presently used in predicting the refractivity is the Central Radio Propagation Laboratory exponential reference atmosphere developed by NBS. [2] This model is based on the finding that the refractivity at high altitude is well correlated with the refractivity at the surface of the Earth. In general, the index decreases with height, and therefore, when a wave is passing from a lower to an upper layer it bends downward, and when it is passing from an upper to a lower layer it bends upward. Under these conditions, not only the apparent position of a source outside the lower atmosphere appears at an elevation angle greater than that corresponding to the true position, but also the effective path length (distance between transmitting and receiving stations) becomes longer than that in the free space. With a priori knowledge of the refractive index (i.e., temperature, barometric pressure, and humidity), the angular and path length deviation can be compensated, which greatly reduces the refractive bias.

Fluctuations about the average refractive index along the transmission path may be expected because of the presence of inhomogeneities in the troposphere. This will introduce fluctuations in the effective path length and phase distortion. The phase distortion will also affect the stability of frequencies transmitted through the troposphere.

Atmospheric noise arises from the emission of electromagnetic energy by the atmospheric gases and precipitation. Since a good absorber is also a good emitter in a uniform and thermodynamic equilibrium medium, both water vapor and oxygen absorb, emit, and scatter energy in accordance with Kirchhoff's law. Using the principle of conservation of energy, a radiative transfer equation can be derived, which describes the radiation field in the atmosphere. The intensity of this radiation is usually represented by an equivalent black-body temperature. In practice, the tropospheric noise can be measured with a radiometer and low-noise receiver. Since the performance of either communication or navigation systems is measured by the signal-to-noise ratio at the receiver, it is quite important to know the amount of sky noise contribution in the total noise level of the overall system.

3. Description of Research

In the lower-frequency region, such as VHF or UHF, many tropospheric effects on earth-space communications are well understood, and thus can be either compensated or neglected. However, there still exists an unsolved problem regarding the random fluctuations in the dielectric constant of the troposphere. These fluctuations will cause random wave scattering and therefore introduce variations in the amplitude, phase, angle of arrival, and polarization of the wave. In future communication system designs, it seems certain that higher-frequency systems, such as millimeter wave and optical frequency bands, will be predominant. Unfortunately, the effects of the fluctuations in the dielectric constant are most pronounced at these frequencies.

Theoretical predictions on the variance and spatial correlation functions of amplitude, phase, and angle-of-arrival fluctuations have been carried out by various methods. Because of the complexity of the problem, a number of approximations were often used in solving the problem theoretically; consequently, it is usually impossible to accurately ascertain the effects that the approximation has on the solution or to determine the ranges of validity. Experimental verifications of theoretical predictions in the following areas are needed:

1. The probability distribution of the amplitude fluctuation. The application of the central limited theorem in the derivation of the logarithmic amplitude equations leads to the prediction of a log-normal distribution of the amplitude. In practice, however, it can also be argued that a Rayleigh or Rice-Nakagami distribution for the amplitude fluctuations is closer to reality than the assumption of normal distribution.

2. The variance of the amplitude, phase, and angle of arrival. The theory developed in Reference 3 predicts that δ^2 approximates $k^{7/6}$ where δ^2 is the variance of the amplitude and k is the spatial wave number. The region of validity must also be tested.

3. The dependence of those fluctuations on system parameters, such as transmitting beamwidth, receiver aperture size, and wavelength.

The experiment consists of configuring a sequence of spacecraft receivers corresponding to a set of programmed transmissions from each of various ground stations. To provide the most useful data, the transmitting ground stations should be so located that the range of elevation angles from zenith to at least five degrees can be included. The spacecraft receivers must provide for calibration of the receiver's noise level and dynamic range. Signal processing and recording capability must also be provided so that the crew can select the best operations for each measurement circumstance.

The choice of a set of test frequencies is less critical in the centimeter wave range than the millimeter wave range, since only single molecular resonance absorption included. This is the resonance caused by uncondensed water vapor at about 22 GHz. At a frequency not far from this bound at 100 MHz, some propagation effects due to the troposphere and ionosphere may be about equal in magnitude.

The observables in the spacecraft are received signal level, frequency, relative phase, and direction of arrival. These quantities will be measured for the following set of conditions:

Ground terminal elevation angle	Zenith to $\leq$ 5 degrees
Clock time	Day and night
Calendar time	All seasons
Weather conditions at terminal	At least 1 year's sample
Terminal location	Arctic, temperate, and tropical

The additional frequency-choice considerations are:

13 to 32 GHz: Greatest sensitivity to water vapor content

$<$ 3 GHz: Effects of rain may be severe

At 100 MHz: Attenuation (precipitation and gaseous absorption) will exceed $\sim$ 0.08 db one-percent of the time (averaged over continental U.S.)

Additional frequency choices may be considered, namely those that provide the possibility of detecting certain atmospheric pollutants, such as sulfur dioxide, nitrous oxide, nitrogen dioxide, and ozone.

On this basis, it is reasonable to choose for this research carrier the frequencies typified by the following:

500 MHz

2 to 3 GHz

15 GHz

22.3 GHz (absorption peak)

30 GHz

4. Impact on Spacecraft

To avoid the problems of signal acquisition, doppler tracking, and antenna-angle acquisition and pointing on the spacecraft, a stationary-synchronous orbit is recommended. The orbit position should be such that ground stations may be located conveniently to allow elevation angles of, say 5, 7-1/2, 10, 15, 20, 30, 45, 60, and 90 degrees. Large-aperture antennas may be required on the spacecraft, particularly at lower frequencies to enable measurement of the angle of arrival. Spacecraft attitude should be known within 0.05 degree, and its position should be known within 0.01 nmi.

It is likely that crew participation in antenna erection and aiming would be required. Additional tasks would be to set up the proper receiving and recording system in accordance with the established program. Advantage might be taken of certain weather patterns if a ground terminal were in position.

5. Required Supporting Technology Development

This research area will essentially be a continuation of on-going programs, such as Advanced Applications Flight Experiments. Consequently, little or no new required supporting research and technology are envisioned.

7. References

1. J. W. Ryde and D. Ryde. Attenuation of Centimeter Waves by Rain, Hail, Fog, and Clouds. General Electric Co., Wembley, England, 1945.

2. B. R. Bean and G. D. Thayer. Central Radio Propagation Laboratory Exponential Reference Atmosphere. Journal of Research of the National Bureau of Standards (U. S.), November-December 1959.

3. J. W. Strobehn. Line-of-Sight Wave Propagation Through the Turbulent Atmosphere. Proceedings of the IEEE, August 1968.

8. Bibliography

Bean, B. R., and G. D. Thayer. Models of Atmospheric Radio Refractive Index. Proceedings of the IEEE, May 1959.

Straiton, A. W., and C. W. Tolbert. Anomalies in the Absorption of Radio Waves by Atmospheric Gases. Proceedings of the IEEE, May 1960.

Thayer, G. D. A Formula for Radio-Ray Refraction in an Exponential Atmosphere. Journal of Research of the National Bureau of Standards (U. S.), March-April 1961.

Tropospheric Absorption and Refraction in Relation to Space Telecommunication Systems. Study Programme 5C/V CCIR, Documents of the XI Plenary Assembly: Vol. II, Propagation. Oslo, 1966.

F. DuCastel, Tropospheric Radiowave Propagation Beyond the Horizon. Pergamon Press, 1966.

Critical Issues Addressed by Research Cluster

5-P-2

TROPOSPHERIC PROPAGATION MEASUREMENTS

5.1.2.3.2.1
What is the path loss between ground terminals and spacecraft as a function of frequency (range of measurements: 1 kHz to 100 kHz) with no visible clouds or rain in the line-of-sight transmission path, and how may variations from the mean path loss be related to, or predicted by, meteorologic data?

5.1.2.3.2.2
What is the relationship between path losses through clouds of various types as a function of frequency? Can path loss be statistically predicted from meteorologic data?

5.1.2.3.2.3
What is the probability distribution of path loss as a function of frequency during rainy weather and how may margin requirements be derived from meteorologic data?

5.1.2.3.2.4
What is the relationship between meteorologic observations and the mean angle of arrival of signal between a ground station and a spacecraft and what is the probability distribution of angle of arrival about the mean value?

5.1.2.3.2.5
What is the probability distribution in arrival time about the mean time delay of signals propagated through the troposphere and how may the time spreading be related to, or predicted from, meteorologic data?

5.1.2.3.2.6
What is the frequency (or phase) uncertainty in signals referred to a stable oscillator due to index of refraction variations in the troposphere and how may it be related to, or predicted from, meteorologic data?

5.1.2.3.2.7
When the phenomena discussed under 5.1.2.3.2.1 through 5.1.2.3.2.6 are best described as stochastic processes, what Earth terminal separations are required to ensure that the variables are uncorrelated? Over what time intervals may the processes be considered as time stationary?

5.1.2.3.2.8

Under meteorological conditions resulting in a highly stratified index of refraction, what is the reflection coefficient as a function of frequency for angles of incidence smaller than the critical angle? Under what meteorological conditions is total reflection encountered?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 5-P-2

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-P-2 -1	Calibrate receiver with reference signal input		3			17-A			1-2			
-2	Setup and calibrate the recording apparatus		3			17-A		120-240	1-2			
-3	Orient antenna to selected ground station		3			17-B		10-30	1-2			
-4	Initiate recording equipment and record signal strength vs. time and date.		5			17-B	1/2 hr	Several Minutes	1			
-5	Evaluate line traces on strip chart recorder		6			17-A		10-30	1			
-6	Perform periodic calibration checks to insure accuracy		4			17-A		up to 120	1-2			
-7	Evaluate data gathered from previous days runs		6			17-A		30	1			
-8	Perform local refractive index soundings and record weather conditions at participating ground station.		--									
-9	Repeat measurements for different conditions		5			--	48/Day	--	--			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS— COMMUNICATIONS

5-P-3 Plasma Propagation Measurements

1. Research Objectives

The primary objective of this research cluster is to investigate the feasibility of transmitting signals from reentry vehicles to a relay satellite instead of to the ground, thereby avoiding the problems associated with transmission through the high-density portion of the plasma produced by the frontal shock wave. Conceivably, the plasma sheath could serve as a reflector of the RF radiation (depending upon the transmitted frequency), thus providing effective antenna gain in the direction of the satellite relay. This, of course, depends upon geometry, wavelength, and shape of the shock-wave-induced plasma sheath.

The successful demonstration of this technique will provide inputs necessary to establish the requirements of future data-relay satellites.

Secondarily, the objective of this research cluster is to obtain practical bounds on the problem of the RF breakdown phenomenon associated with the plasma created by outgassing of spacecraft.

2. Background and Current Status

Plasma sheaths surrounding space and reentry vehicles are produced by the heating of the atmosphere (to the point of ionization) as a result of the shock wave propagated by a reentry vehicle, the exhaust of propulsion engines, outgassing of the vehicle and its components, and nuclear and solar radiation.

Attenuation of RF signals by the thermally ionized atmosphere (plasma) surrounding a reentry vehicle is of principal concern, not only because of loss of communication during the blackout period but also because of the appreciable length of time during which it occurs.[1]

The frequency range over which the maximum attenuation occurs is from 10 to 10.8 MHz. Consequently, the main approach in avoiding the blackout problem has been to use frequencies either lower or higher than this band; e.g., X-bands.[2] Such systems have not been operationally implemented, at least not on as large a scale as would be required by the MSFN or STADAN. Either brute force in the form of high peak transmitter power or tolerance of the problem have been applied for most programs.[3]

With the advent of communication relay satellites, it has become possible to provide an indirect telemetry link from a reentry vehicle to the ground -- indirect in the sense that the propagation path is not through the plasma sheath in front of the vehicle but toward the relay satellite. For some vehicle shapes, the plasma sheath may completely surround the vehicle but will be less dense in the trailing area. Consequently, experiments should be conducted to determine the feasibility of the general application of relay satellites to solve the blackout problem.

3. Description of Research

This experiment generally consists of the monitoring of transmissions from a vehicle entering the Earth's atmosphere from a spacecraft or experiment module. Because the general features of the frequency response of reentry plasmas are known, it is possible to place some bounds on the choice of frequencies to be used.

To conduct this experiment, tracking antennas and receivers in the space vehicle or experiment module corresponding to the chosen set of transmitters in the reentry vehicle must be configured. Within the reentry vehicle, certain quantities must also be measured and recorded. Principal among these are the complex VSWR at the transmitting antenna during the reentry, vehicle attitude, and altitude history. It is assumed that the geometry and composition of the reentry probe are known. It might be useful for the probe to be furnished with a mass spectrometer to obtain an in situ measurement of outgassing species that would contribute to the ionization. Vehicle altitude, as well as velocity profile and meteorological conditions, can be obtained from simultaneous ground observations. The space observation platform (station or experiment module) will contain recorders and telemetry equipment for either real-time or delayed transmission to data-readout terminals on the ground. The general configuration for these experiments consists of relatively broadbeam (about 10 degrees) antennas on the reentry probe, and probably narrower beam (2 to 5 percent) tracking antennas on the spaceborne platform.

Signal-strength measurements should be made for two orthogonally, linearly polarized signals. These measurements of signal strength, although properly reduced, may not produce highly deterministic results because of the uncertainties in the contributing variables. Depending upon the progress made in obtaining statistically well-behaved results, it may be desirable to consider instrumentation beyond the monitoring of the received signal strength. For example, it would be very useful to obtain such data as:

1. Angular dependence of frequency response of reentry plasma. Broadbeam antenna on probe-multiple observing platforms (experiment module and subsatellite.)

2. Angle of arrival changes due to diffraction of radiation by finite reentry plasma boundaries.

3. Effect of dispersion (frequency dependence of phase velocity) on data rate. This can be caused by either the dispersion indicated in item 2 above or the (probably smaller) dependence of plasma refractive index on frequency, and possibly on the value of magnetic field.

These experiments would require more complex instrumentation in both the reentry probe and the monitoring station. The general requirements would be for transmission of sets of both analog and digital data streams from the probe, and comparison to replicas in the spaceborne receiving station and possibly at the ground. These replicas would be uncorrupted by the reentry plasma.

4. Impact on Spacecraft

The experiments described here have no real-time telemetry data requirements. Autotrack receiving antennas might be called for when frequencies of perhaps X-band and higher are employed. For most reentry geometries. it is likely that broadbeam antennas on both the probe and spacecraft receiving platform could be used. Because there is not a strong requirement for very-narrow-beam antennas, wide-bandwidth antenna response can be obtained, thus easing pointing requirements. Ephemeris control is important in this experiment since the reentry trajectory must satisfy viewing from both the spaceborne platform and a well-instrumented ground station. If two spaceborne receivers are employed (angular response experiment), then a data link between the Space Station (for example) and a remotely located subsatellite would be needed. This would not have to be a real-time link, although such a link might be more desirable than the inclusion of recorders in the subsatellite.

Crew participation and support would include appropriate equipment connection and monitoring of some of the recorded outputs to assist in timely diagnosis of the need for experiment and program modifications. The crew might assist in initial antenna pointing and alignment.

5. Required Supporting Technology Development

The plasma propagation experiment would be more useful if, coincidentally, the effects of using physical and chemical means of modifying reentry plasmas were evaluated. Although not directly a portion of the considerations here, the problem of designing antennas that can survive the range of alternative reentry conditions is an important one.

6. References

1. E.F. Dirsa. The Telemetry and Communication Problem of Reentrant Space Vehicles. Proceedings of the IRE, April 1960.

2. E.A. Brummer and R.F. Harrington. A Unique Approach to an X-band Telemetry Receiving System. National Telemetering Conference, May 1962.

3. J.W. Marini and F.W. Hager. Apollo 6, 7, and 8 Blackout Test Results, NASA-TM-X-63636, July 1969.

7. Bibliography

J.E. Drummond. Radio Propagation in Reentry Plasmas, Boeing D1-82-6098, October 1967.

P.W. Huber and T. Sims. Research Approaches to the Problem of Reentry Communications Blackout. NASA-TM-X-56839, Symposium on the Plasma Sheath. Boston, September 1965.

J.A. Cooper and L.M. Melick. Communication with Hypersonic Vehicles, Sandia Corporation. PB-182611, February 1969.

Critical Issues Addressed by Research Cluster

5-P-3

PLASMA PROPAGATION MEASUREMENTS

5. 1. 2. 2. 5. 2
What is the conductivity, DC breakdown voltage, and RF breakdown voltage of the ambient medium in vented enclosures and in the immediate vicinity of an operating spacecraft?

5. 1. 2. 3. 3. 1
For what frequencies and vehicle orbits does the plasma of interplanetary space produce appreciable attenuation of EM waves?

5. 1. 2. 3. 3. 2
For what frequencies and vehicle orbits are polarization rotations by the interplanetary medium significant?

5. 1. 2. 3. 3. 3
In some circumstances spacecraft design may be simplified if high-voltage power supplies and transmitters could be operated in the vacuum of space. What are the DC breakdown potentials versus gap size of various trajectories of interest?

5. 1. 2. 3. 3. 4
The design of feed structures of antennas for transmission of high RF power as well as the physical layout of transmitter elements exposed to the vacuum of space requires detailed information on RF breakdown in orbit. What are the RF breakdown field limitations for various trajectories of interest versus gap size?

5. 1. 2. 3. 3. 5
The phenomena of 5. 1. 2. 3. 3. 1 through 5. 1. 2. 3. 3. 4 may have a dependence on the solar wind in the vicinity of the spacecraft and hence will be correlated with solar activity. How do plasma-related effects vary with time and spacecraft location? Can the magnitude of the phenomena be predicted from solar observations?

5. 1. 2. 3. 3. 6
The prediction of plasma effects on communication signals is currently based on incomplete knowledge of the physics of the interplanetary medium. Are propagation anomolies present which can only be explained by more complex models of the propagation path?

Table 1

CREW ACTIVITY MATRIX †

RESEARCH CLUSTER NO. 5-P-3

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-P-3 -1	Deploy antennas and perform checkout of antennas, preamps, receivers and recorders.	X-Band Parabolic Antenna	3			21B and 17 B	Initial	120-300	1-2			
-2	Checkout system with calibrated signal source		4			17-A	Once/ Setup	30 channels 60/channels	1-2			
-3	Point or steer antennas to target		5			17-B	As Req.	10-30	1-1			
-4	Activate system and record data		5			17 A	Continu-ous	30	1			
-5	Observe re-entry trajectory with optical equipment		7			17 A	1-3 Per Mission	10-15	1			
-6	Check data records and report results to mission communicator		5			17A	Every 4 Hrs	30-60	1			
-7	Store records for later analysis		8			17A		--	1			
-1A	(Deploy satellite)		3			21-B						

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

DO NOT REPRODUCE

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-P-4
MULTIPATH MEASUREMENTS

RESEARCH CLUSTER SYNOPSIS--COMMUNICATIONS

5-P-4 Multipath Measurements

1. Research Objectives

The general objective of this research area is to measure statistical properties of signals simultaneously received over multiple propagation paths between terrestrial users and spacecraft for all frequencies proposed for space repeater communication and navigation systems. The experiment will obtain fundamental data for predicting multipath signal reception as a function of aircraft attitude, elevation angle to the signal source, and the type of terrain. This information is required to develop satellite-aircraft communications techniques for future navigation and traffic control systems.

The multipath measurements to be performed are well suited for use in experimental and theoretical efforts designed to improve the performance of existing and future communication and navigation satellite systems. The measurements are also well suited for experimental verification of theoretical results used in designing future spacecraft systems.

2. Background and Current Status

Communication links involving satellites and aircraft with relatively widebeam antennas encounter multipath transmission and fading, expecially where the aircraft is at a high attitude and over water. The situation is probably most severe when the satellite is near the horizon, as viewed from the aircraft. Similarly, the effects of multipath must be considered when a signal transmitted from a user satellite is scattered by the Earth before it reaches a tracking and data relay satellite (usually in stationary orbit). The problem in this case is that scattered signal interfers with the signal that proceeds directly from the user satellite to the relay satellite.

In designing communication and navigation systems under conditions of severe fading, a sufficient margin for degradation must be included to meet a specified level of performance, and the use of diversity transmission should be considered to keep the margin within bounds of equipment capability and cost.

Communication and ranging are two of the most vital support operations in connection with spacecraft systems involving satellites and aircraft. In spite of this, equipment designed to measure the characteristics of the channel can only rarely be placed aboard a spacecraft because of the great competition for the available payload by all interested parties. Channel measurements, therefore, can usually be obtained only by analyzing incidental data from the operating communication and ranging links. Fading and multipath conditions occur most frequently during powered flight and when the spacecraft is close to the horizon. This condition is therefore usually of very short duration, typically a minute or less, which does not allow the system designer much time during which he can modify the system to improve its performance during these critical periods. One technique that allows the system designer to try different approaches to optimize the system performance is to measure path loss, fading characteristics, and relative signal strength from direct and reflected signals to aircraft at various altitudes.

To date, very little experimental data exists on the nature of the multipath or the fading experienced over the aircraft-to-satellite communication link, although some work has been done, utilizing L-band and VHF/UHF satellites. In practice, the actual multipath may be a varying combination of specular and diffuse reflections. Therefore, different statistical fading models, such as Two-Ray, Rayleigh and Ricean fading, can be considered relative to transmission performance, and the design allows a sufficient margin for degradation to meet a specified performance in the system.

In the past, the majority of the work has been directed toward studying the so-called long-term variations in received signal strength. Now, with some degree of confidence, a design engineer can statistically describe or predict the hourly, daily, or yearly variations in the average received signal level of most radio propagation circuits. With the advent of todays sophisticated communications systems, a renewed interest has been directed toward understanding the so-called short-term perturbations that occur on time scales of seconds or minutes.

3. Description of Research

The scope of an experiment may be limited by time and sponsor requirement to a particular type of controlled communication circuit utilizing a multitransponder satellite as the satellite relay. The propagation channel may be an aircraft-to-satellite link, satellite-to-ground link or aircraft-to-ground link. Particular attention may be given to finding effects of fading depths, fading rates, average signal strengths, and correlation bandwidths on the performance of a modem. A meaningful computer simulation may be performed with the statistical data so obtained. An experimental program that compared the minimum probability of error with the theoretical computer simulation results would certainly be beneficial. Of particular interest in such a series of tests would be the performance of various modem receivers.

Measurements of multipath spread and frequency spread for an actual propagation channel would also provide valuable data.

The multipath tests will be conducted at various frequency bands in the air-traffic user environment with spacecraft transmitters at several altitudes and orbital inclination, and the receiver equipment located in jet-transport user type aircraft. The flight path will include multiple flights over various terrains and with different geometries of the receiver aircraft with respect to the spacecraft. A three-band receiving antenna configuration for

VHF-, L-, and X-bands is required for the multipath signal measurements. The tests will be conducted over all kinds of terrain, including oceans in different sea states. Data from the multipath receivers will be recorded on the aircraft and processed postflight, along with the overall simulation of the system.

Sufficient data and analyses (with some important exceptions) are available for partial design of individual and, in some cases, multiple radio links for the satellite-aircraft system. Lacking is a complete model that integrates the performance of all the various required elements, including frequency selection, data processing, message format, timing, and bit rates, for a physically realizable system. Although it is possible to approximately calculate the performance of the various types of links proposed, including some consideration of attrition, recently developed computer methods suggest the possibility of actually simulating the complete system. With the information available from all previous studies, it should be possible to very closely approach the performance of the system, using various deployments, deployment separations, antennas, modems, satellites, coding, channel fading (propagation path), and characteristics. Since practically all of the inputs would be based on experimental data and confirmed theoretical analyses, it is believed that a Monte Carlo simulation would come very close to approaching the performance that could be measured in an actual test. The simulation, of course, would permit much greater flexibility in changing the input data and conditions. Therefore, the outputs of the study should indicate not only the particular systems that are feasible, but also the systems or combinations of systems that would meet performance and cost requirements. With these data, formalized system requirements and system specifications can be readily established.

It appears possible to simulate the following subsystems and parts of the system:

1. Receivers

    A. IF filters

    B. Energy detector

    C. Integrate and dump filter

    D. Error decision network for both bit and message errors

    E. Multiple receivers for diversity and frequency hopping.

2. Transmitters and Channels (Propagation Path)

    A. Signals from single or multiple transmitters, including modulation, bit rates, message periods, and coding formats.

B. Channel characteristics, including:

(1) Path loss

(2) Fading characteristics

(3) Time availability

(4) Confidence level (including uncertainties other than path losses)

C. Antenna efficiency and directivity

D. Location and separation of satellites

3. Data Processing

A. Simulated function of proposed data-handling computers

B. Simulated timing and delay in relaying modes

4. Satellite

A. Simulated satellite receiver

B. Simulated satellite transmitter

As noted previously, the above items have been satisfactorily simulated in one form or another. No attempt has been made, however, to integrate all of the items into a complete system to determine the system performance. Since most of the methodology is available and the potential results extremely useful, it is desirable to attempt simulation of the system.

4. Impact on Spacecraft

Spacecraft orbit altitude and inclination are not critical but should be selected to provide coverage of heavily traveled air routes, such as the North Atlantic and Continental U.S. The relative geometry of the satellite and aircraft antenna pointing should be conducive to multipath propagation conditions.

The role of man in this experiment will consist of selecting the desired frequency band, erecting and pointing the antennas, aligning and calibrating the equipment, and monitoring the progress of automatic onboard data (signal strength) recording and quick-look displays for determining validity and completeness of data.

5. Required Supporting Technology Development

Although most of the data and analysis required to perform the experiment are available, additional studies are required. Information and some experimental data are required in the following areas:

1. Fading characteristics for aircraft-to-satellite, satellite-to-aircraft, ground-to-satellite, and satellite-to-ground paths.

2. Preliminary study of the modem and receiver characteristics required for all links.

3. Additional experimental path loss data on ground-to-ground paths.

4. Extension of configuration comparison studies to links other than direct and simulcast.

5. Most-probable message formats and lengths.

6. Timing concept and constraints.

7. Data processing and memory requirements.

8. Limited atmospheric noise studies if HF and MF are still considered for possible use.

5. References

1. F. E. Bond and H. F. Meyer. Fading and Multipath Considerations in Aircraft-Satellite Communications Systems. AIAA Paper 66-294, May 4, 1966.

2. D. G. Brennan. Linear Diversity Combining Techniques. Proceedings of the IRE, June 1959, pp. 1075-02.

3. J. A. Aselbine, A. R. Mancini, and C. Sarbure. A Survey of Adaptive Control Systems. Transactions of the IRE, PGAC-6, December 1958.

4. P. R. Stromer. Adaptive or Self-Optimizing Control Systems - A Bibliography. Transactions of the IRE, PGAC-4, No. 1, May 1959.

5. R. Price and P. E. Green, Jr. A Communication Technique for Multipath Channels. Proceedings of the IRE, Vol. 46, 1958.

6. T. Kailath. Optimum Receivers for Randomly Varying Channels. Proceedings of the Fourth London Symposium on Information Theory, Butterworth Scientific Press, London, 1961.

7. J. R. Juroshek. Analysis of a Propagation Channel for a Digital Communication System. Technical Memorandum ERLM-ITS 218, ESSA Research Laboratories, Institute for Telecommunication Sciences, December 1969.

Critical Issues Addressed by Research Cluster

5-P-4

MULTIPATH MEASUREMENTS

5.1.2.3.5.1
How do fading rate and depth of fades depend upon the altitude of an aircraft in communication with a spacecraft?

5.1.2.3.5.2
What are the specular and random fading components of multipath signals for various types of terrain overflown by an aircraft for space communications links?

5.1.2.3.5.3
What is the dependence on elevation angle of the satellite from the aircraft of the specular and random components of multipath signals?

5.1.2.3.5.4
How do fading statistics depend on the selection of carrier frequency?

5.1.2.3.5.5
What is the probability for a multipath signal to exceed any given fraction of the single-path free-space signal under various combinations of 5.1.2.3.5.1 through 5.1.2.3.5.4?

5.1.2.3.5.6
What is the probability distribution of the fading rate when the received signal is smaller than a given fraction of the single-path free-space signal measured over the duration of the fading period?

5.1.2.3.5.7
What is the minimum separation of two signals for which multipath fading is uncorrelated?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 5-P-4

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-P-4 -1	Deploy antenna, and perform system checkout		3			17 B	Once/ Run	60-300	1-2			
-2	Calibrate equipment with appropriate signal source		4			17 B	Once/ Run	60	1-2			
-3	Select desired frequency band - coordinate with aircraft and ground stations		5			17 A	As Req.	20	1-2			
-4	Steer antenna to desired attitude		5			21 or 17 A	As Req.	30-60	1			
-5	Initiate recording equipment		5			17 A	Continuous	60-120	1			
-6	Monitor operation of automatic data recorder for validity and completeness		5			17 A	Every 4 Hrs	30-60	1			
-7	Observe meteorological conditions in area under investigation		7			17 A	As Req.	10-20	1			
-8	Adjust equipment as required to establish range of data and repeat, if necessary, Steps 3 through 7		4			17 A/B	As Req.	10-60	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

Do NOT REPRODUCE

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-TF-1
SPACE DEPLOYMENT AND CALIBRATION

RESEARCH CLUSTER SYNOPSIS– COMMUNICATIONS

5-TF-1 Space Deployment and Calibration

1. Research Objectives

The primary objective of this research area is to provide a manned spacecraft facility to fulfill the required test and calibration functions of communications and navigation equipment, as well as the deployment (erection, alignment, and test) of space antenna structures. Development and manned operation of the space laboratory facility will comprise a sophisticated advanced technology experiment aimed at investigating a means of experiment integration, which is significantly independent of experiment definition.

An additional objective of this facility is to determine the feasibility of using the space environment for equipment calibration and alignment, such as measuring receiver noise figure, using either cold space or celestial sources as references.

2. Background and Current Status

Each of the 14 scientific research clusters includes equipment comprised of various sensors, antennas, receivers, and recorders that require initial and periodic calibration and test. Some of these research clusters—notably 5-N-1 Terrestrial Noise Measurements; 5-N-2 Noise Source Identification; 5-P-2 Troposphere Propagation Measurements; 5-P-1 Ionosphere Propagation Measurements; and 5-P-4 Multipath Measurements—require the erection, alignment, test, and calibration of large antenna structures. To accommodate the frequency range required in these experiments, changeable antenna feeds have been proposed; if they are implemented, they will require extravehicular activity for installation and must be recalibrated before the beginning of the experiment. Therefore, a space laboratory dedicated to the research clusters mentioned above and having the requisite support capability is desired.

3. Description of Research

In the assembly and preparation of experiment instrumentation, the initial checkout will require apparatus calibration. This may also entail some external activity (extravehicluar) to erect antennas, install feeds, interconnect components, and make preliminary baseline measurements. The exact treatment of particular experiments depends on a thorough preplanning of astronaut activities for each research group. The method used necessitates a detailed experiment design and the preparation of a test plan and procedures to be followed. Reliable astronaut performance may require substantial training in the precise measurement techniques and an understanding of the parameter's sensitivity to fluctuations in a changing space environment. The general space laboratory facility must be equipped to support each of the experimental group requirements when assigned to a given mission.

The methodology to be developed will cover deployment of antennas, testing and calibration of antennas, visual observation of flexible structures, inspection for environmental effects, and repair through replacement of components.

4. Impact on Spacecraft

Essentially, the requirements that evolve from this research cluster comprise the requirements for a space vehicle. The laboratory facility should be equipped to enable the astronaut to conduct equipment transfer, setup, erection, assembly, interconnection, and calibration actions prior to beginning the experiments. The variety of experiment measurement parameters is identified in each of the 14 research cluster synopses.

5. Required Supporting Technology Development

The requirements of each of the 14 research clusters dealing with science and technology critical issues are described separately elsewhere. Erection of antennas used by various experimental configurations may require extravehicular activity, and the particular techniques will depend upon a selection from many possibilities. Special handling procedures, tools, and even remote manipulators may be employed for placement and removal of externally mounted components, and for the maintenance, repair, assembly, and test of large antenna systems. The technology to accomplish these tasks will require a continuing design and development effort.

Astronaut training is mandatory for complex extravehicular activity. Test planning and experiment procedures depend on specific mission requirements and must be defined in much greater detail prior to launch.

6. REFERENCES

1. Electronic Instrumentation Techniques and Equipment. NASA SP-5901 (01), Office of Technology Utilization, 1967.

2. C. C. Couchman. Laboratory Considerations for a Scientific Manned Space Station. AIAA No. 63-251, North American Aviation, Inc., June 1963.

3. Definitions of Electrical Terms (Instruments, Meters and Meter Testing). American Standards Association May 1957.

4. Aerospace Measurement Techniques. NASA Sp-132, July 1966.

Critical Issues Addressed by Research Cluster
5-TF-1

SPACE DEPLOYMENT AND CALIBRATION

5.1.1.2.1
Special Interest TV

5.1.1.2.2
Educational TV

5.1.1.2.3
Teleclub Systems

5.1.1.2.5
Direct TV to Homes

5.1.1.3.1
Connection of Major Regional Centers (libraries)

5.1.1.3.2
Communication Between Major Centers and Geographical Areas With Poorly Developed Communications

5.1.1.3.4
Transmission of High-Resolution Images Such as X-Ray Photos

5.1.1.4.1
Store-and-Forward Memories For Satellites (Millions of Bits)

5.1.2.2.5.3
Temperature
What is the operating temperature of electronic equipment aboard spacecraft?

5.1.2.2.5.5
Electromagnetic Radiations of Spacecraft Systems
Are conducting and radiating electric fields and currents generated by other subsystems of the spacecraft sufficiently low to have negligible influence on performance of the communications components?

5.1.2.2.5.6
Meteorite Bombardment
What is the rate of erosion of exposed components due to meteorite bombardment?

5.1.2.4.2.1
Large Aperture Antennas

5.1.2.4.2.2
Multiple Transmitting and Receiving Beams

5.1.2.4.2.4
Interferometer Structures

5.1.2.4.2.5
Phased Array Antennas

5.1.2.4.14.1
Deployment of Antennas

5.1.2.4.14.2
Testing and Calibration of Antennas

5.1.2.4.14.4
Inspection For Environmental Effects

5.1.2.4.14.5
Visual Observation of Flexible Structures

5.1.2.4.16.1
System Simulation
May the conclusions of system concept studies be validated without flight of dedicated satellites?

5.1.2.4.16.2
Subsystem Test In Orbit
Do components and subsystems perform satisfactorily in orbit after passing ground simulation acceptance tests?

5.1.2.4.16.3
Space Qualification of Components
Does the interaction of the space environment with materials result in changes in physical or electrical properties which were not predicted, and which are deleterious to system performance?

RESEARCH CLUSTER
NO. 5-TF-1

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-TF-1 -1	Assemble & visually inspect antennas, components, feeds, and test equipment.		3	EVA		21 & 17-B	Initial	60-300	1-2			
-2	Perform initial confidence checks of system		3			17 B	Initial	30 channel 30-60 per channel	1-2			
-3	Turn on receiver and coordinate antenna directivity with ground site.		5			17-A	For each data run	60	1-2			
-4	Adjust antenna pointing when required to acquire ground station.		5			17 B	As Req.	30	1-2			
-5	Observe remote control of antenna boresighting		5			17 B	As Req.	30	1-2			
-6	Record attenuator settings when output meter indicates equal signal strength. Record angle from maximum signal azimuth		8			17 B	For each data run	15	1			
	(Note: This describes only one antenna calibration procedure - does not cover all cases of system demonstrations suggested by systems development and testing, i.e. 5-CS and 5-NS clusters.)											

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

DO NOT REPRODUCE

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-TF-2
DEMONSTRATION AND TEST

RESEARCH CLUSTER SYNOPSIS—COMMUNICATIONS

5-TF-2 Demonstration and Test

1. Research Objectives
The objective of this experiment group is to provide the basic space facility within which ultimate communications and navigation systems, subsystems, materials, and procedures may be fully tested and validated in the end-use space environment prior to operational deployment. It includes activities described under 5-TF-1.

Essentially, the objective is to develop a versatile, manned space-borne laboratory with most of the features of its ground-based counterpart plus the unique features offered by the ambient environment of space; e.g., the realism of system performance testing afforded by evaluating the equipment in the configuration (such as relative geometry) intended for operational use. The fulfillment of this objective would enable more-economical space testing of new and improved communication and navigation services, thus providing widespread benefits through accelerated technological advances.

2. Background and Current Status
It is apparent that research involving all 90 communications and navigation critical issues now listed as having potential application for space laboratory is impossible. Also potentially important is the necessity of providing the capability to accommodate the test and demonstration requirements of the many remaining critical issues not yet meeting the criteria as having immediate potential for space experimentation.

An analysis of man's function for these critical issues shows him primarily as a mechanical manipulator. His presence is justified in that no electro-mechanical analog device with equal manual dexterity and discrimination ability can be built that would offer any advantage in terms of weight, power, size or capability over man himself.

Clearly, the foregoing discussion points up the need for a modular approach to the configuration of the communications and navigation portion of the orbiting space laboratory, in which man can be considered as a subsystem to be used or not used, depending on experiment requirements. He can be used across the entire spectrum of critical issues, not only where his presence has been shown to the essential but also where he can be useful. The advantages in terms of cost, program and system development time, in-situ repair and modification, phenomena detection, and correlation are self-evident.

In summary, unless man himself is under test and is part of the experiment, the primary justification for man in space is for him to provide an integrated and simultaneous effort to resolve broad spectra of space-oriented critical issues in a reconfigurable, modularized space laboratory or test-bed. No single-point communications or navigation experiment or investigation can necessarily provide this justification. On the other hand, when applied to the total range of activity required across the entire list of critical issues, no other subsystem can be as efficient and cost effective as man himself.

The argument could be advanced that all of the work to be performed by man-in-space could be handled by the crew of the logistic support vehicle (Space Shuttle). Two factors mitigate against such a philosophy. The Apollo program, for example, used crew members who were primarily scientists and engineers and were, secondarily, highly-skilled pilots. The expressed intent for the space shuttle is to employ crewmen who are primarily trained as pilots and would not necessarily have the skills necessary for operation, maintenance, or reconfiguration of the space laboratory. Finally, if the sheer quantity of required activity were to be compared with the relatively short on-station time of the space shuttle, the results would probably show that such a course of action is not feasible, even if given the special skills required.

3. Description of Research

The test facility must provide accommodation for the majority of the critical issues of the communications and navigation disciplines, and consequently, a description of this facility must encompass the fourteen remaining research clusters.

It is useful, in order to establish basic requirements for the orbiting laboratory, to consider the activities involved in performing the communications and navigation experiments. Onboard the test facility, the following types of communication activity will be evident:

1. Operational communications (external).

2. Communication links required for normal operation of the spacecraft.

3. Experiment communications (external).

4. Communications necessary to exchange information and transfer data related solely to on-going experiments, other than communications-oriented experiments.

5. Experiments, investigations, and measurements related to the resolution of communications critical issues identified under the general headings of Environment, Propagation, and Resource Management.

6. Design verification of communications system elements and total systems developed under the general heading of Technology to satisfy user requirements.

7. Communications internal to the orbiting space laboratory, which are extensions of, or are in addition to, the above as part of the normal orbiting space-laboratory house-keeping requirements.

The field of navigation and traffic control may be similarly treated, with the following types of activity:

1. Operational navigation.

2. Unique navigation requirements, temporarily imposed by non-navigation-oriented experiments.

3. Experiments, investigations, and measurements related to the resolutions of navigation and traffic control critical issues for both Earth-oriented and space-oriented systems.

4. Design verification of the navigation and traffic control system elements and total systems that are developed to satisfy user requirements.

4. Impact on Spacecraft

The payload for the test facility (in terms of test and measurement equipment) must reflect the current grouping of experiments to be performed and meet the accuracy, range, and interface requirements of the measurements specified in each group. The facility must then provide the following functions:

1. House and conduct selected communications and navigation experiments.

2. Perform developmental simulation, testing, and demonstration of candidate systems (such as broadcast, information netting, and data collection).

3. Perform black-box space-environmental qualification testing.

4. Perform environmental life tests of new materials and components.

5. Provide cooperative communication support to other experiments and disciplines.

6. Operate the remote maneuvering subsatellites.

7. Reconfigure instrumentation assemblies in consonance with new experiment measurements.

8. Maintain, repair, and calibrate experimental and other communication equipment.

To perform these functions, the facility should have a basic configuration, which will not change significantly over the life of the laboratory. The basic configuration is then made compatible with specific experiment groups by the installation and removal of modules, and the rearrangement of interconnections.

The following crew requirements suggest themselves as prerequisites for operating any permanent (long-term) large-scale space facility that has the primary function of serving as a test-bed and observation platform:

1. Capability to reconfigure the test-bed in accordance with current experiments and mission requirements.

2. Capability to set up, install, or remove components and modules as required, both internal and external to the orbiting space laboratory, and employing man's correlating observations.

3. Capability to operate, not only installed experiment measurement equipment, but very precisely to operate and control (relative to the orbiting space laboratory) experiment-oriented devices not physically a part of the orbiting space laboratory. (Remote Maneuvering Subsatellite (RMS) is cited as an example.)

4. Capability for nonscheduled adjustment and modification.

5. Capability for failure diagnosis, repair, and calibration.

6. Capability to monitor the test and to evaluate measurements.

5. Required Supporting Technology Development

The required supporting research and technology to accommodate the 14 research oriented investigations is discussed in each respective research cluster. As far as the facility itself is concerned, this space laboratory capability will essentially be a follow-on activity of current programs, such as Skylab, Space Station, and Experiment Module.

6. References

1. Skylab Program Technical Summary. NASA, OMSF, June 1970.

2. Space Station Phase B Definition. North American Rockwell, Space Division, NASA Contract NAS9-9953, July 1970.

3. Experiment Module Concepts Study. General Dynamics, Convair Division, NASA Contract NAS8-25051, October 1970.

7. Bibliography

Electronic Instrumentation Techniques and Equipment. NASA SP-5901 (01), Office of Technology Utilization, 1967.

Couchman, C. C. "Laboratory Considerations for a Scientific Manned Space Station." AIAA No. 63-251, North American Aviation, Inc., June 1963.

Critical Issues Addressed by Research Cluster

5-TF-2

DEMONSTRATION AND TEST

5.1.1.2.1
Special Interest TV

5.1.1.2.2
Educational TV

5.1.1.2.3
Teleclub Systems

5.1.1.2.5
Direct TV to Homes

5.1.1.3.1
Connection of Major Regional Centers (libraries)

5.1.1.3.2
Communication Between Major Centers and Geographical Areas With Poorly Developed Communications

5.1.1.3.4
Transmission of High-Resolution Images Such as X-Ray Photos

5.1.1.4.1
Store-and-Forward Memories For Satellites (Millions of Bits)

5.1.2.2.5.1
Pressure
How does pressure change as a function of time in vented enclosures in an operating spacecraft?

5.1.2.2.5.3
What is the operating temperature of electronic equipment aboard spacecraft?

5.1.2.2.5.4
How do physical and electrical properties of materials of communication equipment change during operation in the space environment?

5.1.2.2.5.5
Are conducting and radiating electric fields and currents generated by other subsystems of the spacecraft sufficiently low to have negligible influence on performance of the communications components? 16

5.1.2.4.14.3
Repair Through Replacement Of Components

5.1.2.4.14.4
Inspection For Environmental Effects

5.1.2.4.16.1
May the conclusions of system concept studies be validated without flight of dedicated satellites?

5.1.2.4.16.2
Do components and subsystems perform satisfactorily in orbit after passing ground simulation acceptance tests?

5.1.2.4.16.3
Does the interaction of the space environment with materials result in changes in physical or electrical properties which were not predicted, and which are deleterious to system performance?

Table 1

CREW REQUIREMENTS MATRIX

RESEARCH CLUSTER NO. 5-TF-2

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-TF-2	Receive equipment		3			0-C	1/90 day	120	1	1974	1 yr	
	Unpack and store equipment		3			0-C	1/90 day	60	1	1974	1 yr	
	Install equipment		3	EVA		21-A	1/90 day	180	1	1974	1 yr	
	Calibrate equipment		4			17-B	1/90 day	60	1	1974	1 yr	
	Integrate subsystems		4			17-B	1/90 day	120	1	1974	1 yr	
	Checkout systems		6			17-A	1/90 day	180	1	1974	1 yr	

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS – COMMUNICATION

5-CS-1 Millimeter Wave Demonstration

1. Research Objectives
The basic objective of this research cluster is the acquisition of data for the evaluation of millimeter wave system techniques and system components under actual space environmental conditions. Although programs are currently underway (for example, the ATS-5 spacecraft 15/31 GHz experiment) for evaluation of Earth's atmosphere as a propagation medium for millimeter waves, the proposed research will provide a means of obtaining supplementary data and will permit wide variation in system parameters to obtain additional information.

One of the more important objectives will be determination of the effect of adverse atmospheric conditions on system bandwidth requirements and of the extent of atmospheric scattering of millimeter waves propagated parallel to the Earth's surface and marginally within the Earth's atmosphere. The measurement process will permit the testing of methods for locating and tracking narrow antenna beams and will allow the acquisition of data on the performance of various techniques for accomplishing this.

Widely diverse demonstrations of millimeter wave systems will be possible, both in wideband (high data rate) satellite-satellite links and in Earth-satellite communication.

2. Background and Current Status
Since the aperture dimensions of high-gain antennas needed for transmission and reception are directly proportional to wavelength, it is apparent that size requirements for a communication system may be reduced when millimeter wave frequencies are used. At the same time, operation at these frequencies provides increased spectrum availability for wideband system operation.

The large spreading loss encountered during space transmission, and the atmospheric losses encountered during Earth-satellite transmissions, require the use of high-gain, narrow beamwidth antennas. The narrow beams thus permit spatial separation between links. A channel thus may be simultaneously occupied by many users while retaining privacy and negligible interference levels. Extremely wideband operation (1 GHz or more) of antennas, transmitters and receivers is within the state of the art, but the ability of an Earth-satellite link to support this bandwidth is uncertain.

The utility of wideband systems in across space satellite-satellite transmission requires further investigation. Millimeter wave or laser systems operating at frequencies for which transmission is strongly attenuated by the Earth's atmosphere is currently considered to be achievable. Operation at these frequencies makes strong reception from ground stations unlikely due to the opaqueness of the atmosphere and reduces the probability of channel interference. At the present time, hardware for millimeter wave systems is in a far more advanced state of development than is laser system hardware and, although laser systems may ultimately offer greater bandwidth, it is certainly reasonable to use a millimeter system for this application. Operation at a frequency of 60 GHz is most desirable since a strong oxygen absorption band exists at this frequency.

Earth-satellite transmission may be strongly affected by variations in the propagation path as a function of frequency and antenna elevation angle. The two primary mechanisms which cause this attenuation are (1) absorption due to electromagnetic wave coupling with molecular oxygen which possesses a magnetic dipole moment and (2) absorption due to electromagnetic wave coupling with water vapor which has an electric dipole moment. The window regions near 35 GHz and 94 GHz are suitable for Earth-satellite links and for clear weather the difference between the attenuation at 90 degrees and 5-degrees elevation angle for the 35-GHz band is only 3 db. Precipitation in the form of rain, snow, fog, etc and concentration of water vapor (clouds) significantly affects the path attenuation by increasing the absorption and by scattering the millimeter energy by the precipitation particles. Atmospheric attenuation in the 10- to 100-GHz band is a function of rainfall rate and fog/cloud densities. For long propagation paths typical of an Earth-satellite link, several conditions may exist simultaneously so that the attenuation calculation (given the conditions along the path) must be made using piecewise integration. In designing the millimeter wave link, the additional transmitter power required to overcome the increased attenuation due to precipitation must be evaluated on a statistical basis. A value of 99.9 percent link availability is generally considered acceptable and thus, the average rainfall corresponding to 0.1 percent of the hours for the particular location would be chosen.

In addition to the absorption phenomenon, diurnal and seasonal variations in the refractive index along the propagation path may cause signal fading and ray bending which is difficult to predict. Signal fading would be significantly more pronounced on a hot, dry, windy day than on a still, foggy day. Ray bending for an Earth-satellite link is generally negligible for elevation angles greater than 10 to 15 degrees.

Some current measurement programs and problems are described in the following paragraphs.

The meteorological factors involved in the atmospheric attenuation of millimeter waves are atmospheric hydrometers, i.e., fog and the various forms of precipitation, rain, snow and ice. A considerable amount of theoretical and experimental work in this area has been accomplished for terrestrial propagation paths.

As previously mentioned, measurements are currently being made on an Earth-satellite link using the NASA/GSFC ATS-5 satellite at a downlink frequency of 15.3 GHz with an uplink frequency of 30.65 GHz. Test data have been made available by NASA in a report published in March 1970. As a result of an unfortunate tumbling condition of the satellite, short-term amplitude and phase data could not be obtained, but long-term fading studies, fade duration, etc., were unaffected.

Because of the propagation path attenuation and variations in refractive index versus frequency, a wideband signal may suffer amplitude and/or phase distortion. The medium may be represented by a system transfer function $H(j\omega)$ and if distortion-free transmission is to occur, the medium response must have a constant-amplitude characteristic over the frequency spectrum of the signal and the phase shift must be linear over the same band, i.e., $H(j\omega) = Ke^{-j\omega t}$. If the medium's characteristics were not so dynamic, compensation as applied in physical networks might be attempted for severe problems or critical cases. Measurements of phase coherence are being attempted by GSFC and other organizations participating in the ATS-5 experiment, using the same experimental setup as for the path attenuation study. The ATS-5 signal at 15.3 GHz can be modulated to produce sidebands at ±100 kHz, ±1 MHz, ±10 MHz or ±50 MHz from the carrier. However, results may not be available because the satellite is tumbling and the millimeter wave antennas are not capable of being locked onto the Earth, making the measurement difficult if not impossible. Because of the possible fine structure of the attenuation versus frequency curve at high altitude (minimal pressure broadening effect), wideband signal distortion may be quite severe at 35 and 94 GHz. Consequently, tests in these frequency bands should be conducted for an Earth-satellite link. Additional tests at the uplink and downlink frequencies may be useful to provide data which is supplementary to that obtained from the ATS-5 experiment and the projected ATS-F experiment.

If two antenna beams (one being used to transmit and the other to receive) intersect in a common volume within which hydrometeors are present, interference to the receiver may result (assuming the transmitter and receiver are in the same frequency band). This interference is a result of scattering of the radiated millimeter wave energy by the hydrometeors. Of particular concern is the possible interference to terrestrial users by relay satellite uplinks. The COMSAT CORP is currently performing experiments at 6 GHz, and has formulated plans to investigate the effects at 12 and 18 GHz. Precipitation scatter experiments are generally conducted on the ground since it is the high ERP uplink and close proximity to terrestrial users that cause the potential problem. Downlink power density is limited to $-152 + \theta/15$ dbW/4 kHz/m^2 in the 4- to 6-GHz band by CCIR regulation. It is possible that the 20 and 30-GHz bands will be dedicated exclusively to satellite communications. If so, this statutory regulation will not be imposed nor will the precipitation scatter interference problem exist. Therefore, at this time, precipitation scatter experiments for an Earth-satellite link in this band do not appear necessary.

The potential use of the high-absorption band (60 GHz) for satellite-to-satellite relay to obtain link privacy and minimize Earth-satellite channel interference has been suggested. Attenuation and scattering measurements should be performed in this band to verify predicted values. Detectability of scattered radiation from a satellite-to-satellite relay whose beam is tangent to the Earth's atmosphere should be measured from all aspects.

3. Description of Research

The proposed experiment is part of a broad program of manned space activities which includes setup and calibration of equipment, recording and analysis of test data, extra vehicular activity in connection with antenna boresighting experiments and on-line coordination with ground terminals. With the exception of visual metering checks, the test apparatus may be left unattended in transponding modes for long-duration transmissions. However, manual override of automatic tracking operations may be necessary in the event of equipment malfunction.

Experiments of importance are the measurement of long- and short-term parameters affecting communications transmission and system performance at millimeter wavelengths. Of prime importance are the effect of weather on path attenuation and signal phase coherence, the effect of both of these quantities on system bandwidth requirements and the scatter detectability of 60 GHz transmissions parallel to the Earth's surface.

Two of the more important quantities to be checked under varying conditions of system bandwidth, carrier frequency and inclination angle are amplitude and phase coherence of signals transmitted between the satellite and an Earth station. It is well known that these quantities are strongly dependent on weather conditions and on atmospheric turbulence. Data accumulated over long time periods is certainly essential for a complete understanding of these phenomena, but short-term data showing fluctuations resulting from sudden atmospheric changes is also essential.

It is expected that path attenuation might vary as much as 50 db while carrier phase could exhibit 0 to 180 degree phase changes. Measurement accuracy requirements should be of the order on 0.2 db in amplitude and 2 degrees in relative phase.

While data must be accumulated over a period of several years until all phenomena are well understood, the measurements would be made over time intervals onthe order of a millisecond, with intervals onthe order of seconds between measurements. The total measurement period may run from one-half to one day, the schedule being varied to suit experimental conditions. The emphasis in experimentation will be on transmission effects through the atmosphere whereas the emphasis in the propagation research clusters 5-P-1 through 5-P-4 will be on scattering effects (-1, -2), propagation through plasmas (-3), and multipath effects (-4), respectively.

Variations in range and inclination angle between satellite and ground may be achieved by switching from one ground station to another. It is expected that the pointing accuracy of ground station antennas would have to be in the range of 0.01 to 0.05 degrees and that elevation angles between 5 and 90 degrees might be achieved. Atmospheric path lengths on the order of 100 to 500 nautical miles probably would be encountered, and assuming synchronous orbit, total path lengths on the order of 22,000 nautical miles may be encountered.

Atmospheric disturbances affecting the measurements include sky temperature, atmospheric turbulence, atmospheric molecular resonances, rainfall, fog and cloud density. Experimentally induced disturbances affecting the results include pointing errors, millimeter source phase jitter and excessive receiver noise. Differential attenuation and phase shift caused by atmospheric variations will tend to vary the time of arrival of a phase front, thus reducing signal coherency. Correlation of measured data with theory may be possible, however, since presently available theoretical analyses relate time spreading to atmospheric turbulence, inhomogeneities and index of refraction. These theories are related to resonance phenomena in water vapor and in the oxygen molecule, as well as to gross variations in pressure and temperature.

A Dicke radiometer will be used to map background sky noise and an IF frequency multiplexer will be used to sort out coherent sidebands for phase and frequency measurements. Another measurement of interest is that of phase front arrival time, made using a phased array antenna. An IF cross-correlator also may be used to relate the distortion of more complex communications spectra to locally generated reference spectra. Measurements would utilize the spacecraft acting both as a transmitter and a receiver, with apparatus inside the spacecraft used for IF and data processing functions. Externally mounted equipment requirements include antennas and an antenna-mounted superheterodyne receiver and millimeter wave transmitter. It is expected that the relative signal level might vary over a range of some 40 to 50 db, depending upon experimental conditions, and that the absolute value of the incoming signal might vary from approximately -18 to -68 dbm.

Target illumination is fixed primarily by the beamwidth of the transmitting antenna, which in turn may have considerable influence on the reception of unwanted signals. Spurious external signals may generate erroneous data points, false lock conditions in phase-locked receivers, and may also distort discrete AM and PM sidebands. Unwanted signals also may be generated internally by local oscillators in the instrument package.

4. Impact of Spacecraft

Probably the most important factor influencing the system requirements is the satellite orbit. The type and positioning of orbit is determined primarily by the length of time in which it is desired that the satellite be located in the vicinity of designated ground stations and by the location of the ground stations themselves.

To achieve maximum time in view, with minimum changes in range and with zero relative velocity between the satellite and a ground terminal station, an equatorial synchronous orbit is needed.

The equipment which has been described will weigh approximately 400 lb. and will require an average of 350 w of operating power. Peak power loads of 400 w may occur during approximately 20 percent of the operating period and minimum loads of 300 w may occur for about the same time duration.

A crew of one or two astronauts will be needed to perform tasks necessary for the experiment. The crew should be capable of boresighting and reconfiguring the antenna systems through extravehicular activity which may be required from two to four times per month. These periods of EVA will probably vary in length from one-half to three hours, depending upon task complexity.

5. Required Supporting Technology Development

To implement this experiment, development of high-speed, real time amplitude and phase correlators will be necessary in order to perform real time analyses on the complex signal spectra which will be generated. The analyses will include autocorrelation of experimental data and cross-correlation of experimental data with locally generated spectra.

A theoretical study will be required initially to determine what techniques can be used, how they may be implemented, and how the data from the correlators can be processed and interpreted. Techniques must be developed for processing high-speed signals without the necessity of excessive data bandwidths. The output data must be of such a nature that it can be directly related to communication system parameters such as bit error rate, signal-to-noise ratios, envelope time delay, and harmonic and nonharmonic signal distortion. If proper techniques are used, complete characterization of the propagating medium should be possible.

6. REFERENCES

1. E. E. Altshuler, Earth-to-Space Communications at Millimeter Wavelengths, Air Force Cambridge Research Laboratories, Report AFCRL-65-566, August 1965

2. A. W. Straiton and C. W. Tolbert, Factors Affecting Earth-Satellite Millimeter Wavelength Communications, IEEE Trans., Vol MTT-11, No. 5, pp. 296-301, September 1963

3. W. Holzer, Atmospheric Attenuation in Satellite Communications, Microwave Journal, Vol. VIII, No. 3, pp. 119-125, March 1965

4. J. W. Dees, Millimeter Wave Propagation Experiments from Satellites, Martin Marietta Interdivisional Antenna Symposium, August 1967

5. F. Shimabukuro, Propagation through the Atmosphere at a Wavelength of 3.3 MM. IEEE Trans., Vol. AP-14, No. 2, pp. 228-235, March 1966

6. E. P. Valkenburg and V. E. Derr, A High-Q Fabry-Perot Interferometer for Water Vapor Absorption Measurements in the 100 Gc/s to 300 Gc/s Frequency Range, Proc. IEEE, Vol, 54, No. 4, pp. 493-498, April 1966

7. L. Frenkel and D. Woods, The Microwave Absorption by H_2O Vapor and Its Mixtures with Other Gases Between 100 and 300 Gc/x, Proc. IEEE, Vol. 54, No. 4, pp. 498-505, April 1966

8. L. A. Hoffman, H. J. Wintroub and W. A. Garber, Propagation Observations at 3.2 Millimeters, Proc. IEEE, Vol. 54, No. 4, pp. 449-454, April 1966

9. W. A. Koenig and C. W. Merle, The Influence of Rain and Cloud Attenuation on the Design of a 20- to 30-GHz Spacecraft Communications Repeater, AIAA Paper No. 70-498, April 1970

10. A. Buige and J. L. Levatich, Measurement of Precipitation Scatter Effects on Propagation at 6, 12 and 18 GHz, AIAA Paper No. 70-499, April 1970

11. A. Buige and J. L. Levatich, Propagation Experiments Above 10 GHz for Application to Communication Satellite Systems, AIAA Paper No. 70-500, April 1970

12. F. Carassa, G. Drufuca, and A. Paraboni, The Italian Satellite Sirio-SHF Propagation and Communication Experiments: Scientific Objective and Organization of Experiments, AIAA Paper No. 70-501, April 1970

13. E. E. Reber, et. al., Oxygen Absorption in the Earth's Atmosphere, The Microwave Journal, November 1969

14. E. E. Altshuler, et. al., Atmospheric Effects on Propagation at Millimeter Wavelengths, IEEE Spectrum, July 1968

15. Louis J. Ippolito, ATS-V Millimeter Wave Experiment Data Report, October-December 1969, GSFC Report No. X-733-70-123, March 1970

16. Robert C. Tansworthe, Projected Requirements for Deep Space Communications, IEEE International Conference on Communications, June 9-11, 1969

Critical Issues Addressed by Research Cluster

5-CS-1

MM WAVE DEMONSTRATION

5.1.1.1.1.5.1
How may planetary (or lunar) data relay satellites be employed in Manned Space Flight Mission Support? A lunar or planetary orbiter may relay communications to Earth when the user station is not within line of sight of Earth stations. Experiment requirements: The utility of the lunar libration point should be evaluated by demonstration of the stability of the libration point orbit.

5.1.1.1.1.5.2
How may earth orbiting data relay satellites be employed in Manned Space Flight Mission Support? Geostationary Earth satellites employed as mission data relays can provide nearly continuous coverage of deep-space missions and provide improved angular accuracy for position fixing due to the large baseline for observations.

5.1.1.1.1.5.3
How may cross space data relay satellites be employed in Manned Space Flight Mission Support? Three or four geostationary satellites equally spaced about the equator can provide continuous coverage of both low-orbiting satellites as well as deepspace probes. By the use of 2 cross-space relays to one satellite in view of CONUS, the entire net can be served by one ground station.

5.1.3.2.1
How does circuit quality of MM wave systems for communications between spacecraft compare to the quality of systems being currently employed for various types of service?

5.1.3.2.2
What limitations are placed on MM wave employment on space-to-ground links by atmospheric absorption and refraction?

5.1.3.2.3
Implementation of high data rates in the presently employed bands is limited by both hardware considerations and spectrum crowding. Can MM waves be employed for transmission of data at rates of hundreds of megabits per second? What are the hardware and propagation limits on data rate?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-CS-1 -1	Initiate calibration of equipment through onboard radiometer, modulation test set and monitoring of various critical voltages and currents.		3			17-A	Once per data run	60-300	1-2			
-2	Maintain, repair and replace failing equipment		4			17-B	--	--	1			
-3	Reconfigure equipment as necessary in order to perform new experiments		5			17-A	As Req.	60-120	1-2			
-4	Monitor critical demodulated and swept wave forms	CRT Display	5			17-A	Continuous	5-30	1			
-5	Check graphically recorded data		5			17-A	Continuous	5-30	1			
-6	Perform critical initial measurements such as antenna boresighting, receiver noise figure and bandwidth adjustments, linearity and output power adjustments		3			17-A	Various	30-	1			
-7	Monitor phase and amplitude of signals to optimize processing, encoding and transmission.		5			17-A	Continuous	5-30	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

Do Not Reproduce

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY RESEARCH CLUSTER – COMMUNICATIONS AND NAVIGATION

5-CS-2
OPTICAL FREQUENCY DEMONSTRATION

RESEARCH CLUSTER SYNOPSIS—COMMUNICATIONS

5-CS-2 Optical Frequency Demonstration

1. Research Objectives

The objectives of this research are to:

1. Refine and extend the knowledge and range of data associated with the use of optical frequencies in space communications applications.

2. Ascertain the practicality of wideband, high-data-rate optical communications between a spacecraft in nonsynchronous orbit and a ground station, and between two orbiting spacecraft.

3. Define and characterize the problems in, and the optical device parameters for, optical communications equipment operating in a space environment.

Optical communications offer the advantages of very wide allowable bandwidths and small physical apertures for point-to-point transmission of data in a space environment. Many variables, however, such as atmospheric attenuation and scattering, and spacecraft stabilization requirements, have yet to be established. Data resulting from this experiment are paramount in planning and developing satellite systems for optical space communications, optimizing the use of the total electromagnetic spectrum, and fulfilling NASA's role as space communications consultants to government and industry.

2. Background and Current Status

Over the past few decades, the utilization of radio frequency electromagnetic propagation as a means of communication has very rapidly increased. As this spectrum (100 kHz to approximately 30 GHz) becomes filled, allocation of new bands has become increasingly difficult, and consequently, new bands within the total electromagnetic spectrum must be developed.

Since the permissible modulation bandwidth (or data rate in the case of digital signals) is proportional to the carrier frequency, optical carriers would allow wider bandwidths than carriers within the normal radio spectrum. Further, the physical transmitting and receiving apertures required to give extremely narrow beams (and therefore the high-energy densities at the receiver of a point-to-point communications system) for an optical communications system are much smaller than the physical aperture of even a millimeter wave system. Consequently, the logical place for extending the communications spectrum might be into the optical region.

Disadvantages of the optical spectrum as a communications medium lie in the high-energy absorption and scattering of the beam by particles of atomic size and larger. Variations in the index of refraction over the propagation path resulting from variations in atmospheric temperature, pressure, and density will cause beam bending, making acquisition and observation between the transmitter and the receiver extremely difficult. Random variations in temperature, pressure, and density will distort the transmitted wavefront and result in signal fading and distortion. This means that optical communication for point-to-point contact over the surface of the Earth is virtually impossible except over short distances. Reliable communication at optical frequencies between two points on the Earth's surface requires the use of optical wave guides connecting the transmitter and the receiver.

In spacecraft-to-spacecraft communications, the problems of absorption, scattering, phase distortion, and beam bending are negligible because of the absence of any significant atmosphere. If the two satellites are moving with a relatively high velocity with respect to one another, a doppler frequency shift proportional to the product of the carrier frequency and the relative velocity will occur; and if it is not compensated for in the receiver or the transmitter, it may result in an inability to establish the transmission link. This effect will be negligible if the two satellites are in the same orbital path.

In surface-to-spacecraft communication links, both the effects of the atmosphere and those of a doppler shift may be present. (Doppler shift will not occur if the spacecraft is at synchronous altitude.) For this case, optical frequencies that will minimize the atmospheric effects must be chosen, since windows in the atmosphere are known to exist. One such window occurs in the wavelength region of 10.6 microns, corresponding to the lasing frequency of the carbon-dioxide, nitrogen, helium laser; and ATS-F/G research is under way to develop space-qualified hardware at this wavelength to demonstrate a two-way high-data-rate communications link between the Earth and a synchronous satellite.

Other problems to be investigated through this research cluster are:

1. Problems associated with the precision pointing required by the very narrow beamwidths to acquire and maintain lock-on between transmitter and receiver.

2. Noise problems (since the thermal noise is much greater at optical frequencies than in the microwave region).

3. The effects of cloud and haze coverage of the Earth in surface-to-satellite laser communications links.

4. Diurnal effects on scattering and scintillation due to turbulence in the upper reaches of the atmosphere.

3. Description of Research

This experiment consists of two parts: (1) a space-to-ground link and (2) a space-to-space link. The primary distinction between them is the intervention of the Earth's atmosphere. The experiments, tests, and measurements that will be made include:

1. Signal-to-noise ratio as a function of atmospheric parameters.
2. Signal-to-noise ratio as a function of receiver aperture.
3. Signal-to-noise ratio as a function of zenith angle.
4. Space background noise.
5. Laser power output as a function of both total elapsed time and operating time in the space environment.
6. Temperature and noise figure of the receiver mixer-radiation cooler, as a function of satellite orientation and time of year.
7. Round-trip and one-way data quality compared with a reference microwave link.
8. Effects of the space environment on the laser frequency stability and bit error rate.

It is inappropriate to describe this research in terms of specific laser oscillators, since this technical area is in a state of rapid change. Instead, the approach taken has been to select wavelengths for operation that exhibit the characteristics required to give best system performance. Other components have been identified in a similar manner, although in some cases, specific alternatives can be identified. Some of the equipment and facilities required for this experiment will duplicate that needed for experiments in other radio and communications problems, and can therefore share such equipment except where sharing interferes with necessary simultaneous operation.

Operational wavelengths for these experiments should include 0.45, 0.65, 1.0, 2.1, and 10.6 microns. A common modulating element can probably be used, at least for the first three wavelengths. This represents some compromise in that such an approach may limit the use of alternative modulation techniques. Information to be transmitted will include both wideband analog data and high-data-rate digital information. Heterodyne detection will be used on the 10.6-micron receiver, but projections of detection may be used below about 3 microns. In wavelengths below this, photoemissive detectors with electron multiplication, or solid-state detectors, such as Schottky-barrier devices, will be used.

The optical elements necessary for the research comprise the best defined components for these experiments. Transmitting and receiving optics of about 30 to 60 cm should be adequate for the entire range of experiments. Other optical components, such as transfer lenses, optical spectral filters, beam splitters, and a means for the protection of the equipment from solar radiation, are required and are presently available.

4. Impact on Spacecraft

The major impacts of this research cluster on the space vehicle are:

1. The degree of spacecraft attitude stability and control required for acquisition of the target receiver and maintenance of the communications link once it has been established.

2. The availability of a viewing port unobstructed by the spacecraft's outboard equipment, and having suitable transparency over the entire spectrum of interest (visible through the far infrared).

3. A means of controlling and reducing the hazard of possible eye damage to the crew.

4. Reduction of radio-frequency interference that may be generated within the optical modulator circuits and other subsystems of the experimental equipment.

Because acquisition and pointing of the equipment are very critical to the success of this research, spacecraft attitude and associated rates will be required inputs to the optical tracking subsystem. Structural flexing of the spacecraft must be compensated for if attitude and rate signals are desired from the space vehicle's inertial reference system. If such compensation is impossible, the experiment tracking loop will require a self-contained reference.

Configuration changes of both optical and electronic components will be an important part of the experiment. Further, since relatively little is known about the reliability, life time, and behavior of optical communications components in the space environment, crew participation is vital to the success of the experimentation.

Standard electronic and optical maintenance equipment associated with normal spacecraft activities will be required for servicing and maintaining the equipment and subsystems being used. The research will also require the use of the spacecraft data processing and Earth-to-satellite telemetry.

If the experimental equipment at each wavelength of interest is entirely self-contained, the equipment for each of these wavelengths may be expected to occupy a volume of 35 cu ft, weigh up to 600 lb, and require a power of 500 to 600 w while operating. The total weight and volume for the entire experiment package may be reduced by using common electronic and optical components.

5. Required Supporting Technology Development

To fully implement this research cluster, technical advancement must be made in the areas of:

1. Tunable lasers having high degrees of stability.
2. High-sensitivity, low-noise detector materials and configurations.
3. Optical modulation techniques.
4. Narrowband spectral filters.

6. References

1. Laser Communication System. W. K. Pratt, Wiley, 1969.

2. D. B. Rensch and R. K. Long. Comparative Studies of Extinction and Backscattering by Aerosols, Fog and Rain at 10. 6 and 0. 63 Microns. Applied Optics, Vol. 9, No. 7, July 1970.

3. W. M. Irvine and J. B. Pollack. Infrared Optical Properties of Water and Ice Spheres.

4. F. E. Goodwin and T. A. Zussmeier. J-5 Optical Heterodyne Communications Experiments at 10. 6 Microns. IEEE Journal of Quantum Electronics, Vol. QE-4, No. 10, October 1968.

5. T. J. Gilmartin. 10. 6-Micron Laser Radar Propagation Experiments.

6. A. Goldman, T. J. Kyle, D. G. Murcray, F. H. Murcray, and W. J. Williams. Long-Path Atmospheric Ozone Absorption in the 9- to 10-Micron Region Observed from a Balloon-Borne Spectrometer. Applied Optics, Vol. 9, No. 3, March 1970.

7. P. K. L. Yin and R. K. Long. Atmospheric Absorption at the Line Center of P(20)CO_2 Laser Radiation. Applied Optics, Vol. 7, No. 8, August 1968.

8. W. T. Cathey, C. L. Hayes, W. C. Davis, and V. F. Pizzurro. Compensation for Atmospheric Phase Effects at 10. 6 Microns. Applied Optics, Vol. 9, No. 3, March 1970.

9. G. D. Lukes. Penetrability of Haze, Fog, Clouds, and Precipitation by Radiant Energy Over the Spectral Range 0. 1 Microns to 10 Centimeters. Center for Naval Analyses, May 1968.

Critical Issues Addressed by Research Cluster

5-CS-2

OPTICAL FREQUENCY DEMONSTRATION

5.1.3.3.1
How does circuit quality of optical communications signals transmitted between spacecraft compare to the quality of electromagnetic signals currently used in conventional systems?

5.1.3.3.2
What limitations are placed on employment of optical frequencies on space-to-ground links by atmospheric absorption, refraction, and scintillation?

5.1.3.3.3
How does the actual performance of optical radars and range determination systems compare to the theoretical performance?

5.1.3.3.4
What are the hardware and propagation limitations on the rate at which data can be transmitted at optical frequencies?

(NOTE: Refer also to 5.1.1.1.1.5, Mission Data Relay Satellites)

RESEARCH CLUSTER
NO. 5-CS-2

Table 1

CREW ACTIVITY MATRIX

EXPERIMENT GP/SUB GP	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-CS-2 -1	Stabilize spacecraft attitude		2			21-A	Initial	--	1			
-2	Initiate laser transmitter, program in test signals, and aim the optical system.	Laser Transmitter	3			17-A	As Req.	30-300	1-2			
-3	Program in test signals, activate receiver and adjust system gain.	Laser Transmitter	5			17-A	Once per data run	60	1			
-4	Observe and photograph meteorological phenomenon in area where ground terminal is operating.		5	No cloud cover over ground site.		21-A	As Req.	10-30	1			
-5	Initiate surveillance of area with multi-spectral optical sensors.		5			17-A	Over ground relay site	10-15/run	1			
-6	Record other sensor readings in the event of anomalies.		6			17-B	As Req.	10-20	1			
-7	Monitor recorder output for validity of measurements.		5			17-A	Continuous	10	1			
-8	Monitor operation of experiment sequencer and modify if necessary.		5			17-A	As Req.	5-60	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

DO NOT REPRODUCE

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-NS-1
SATELLITE NAVIGATION TECHNIQUES FOR TERRESTRIAL USERS

RESEARCH CLUSTER SYNOPSIS–NAVIGATION
5-NS-1
Techniques for Terrestrial Users

1. Research Objectives

The general objective of this research group is to evaluate proposed navigation satellite techniques. This evaluation would consist of system performance testing, e.g., establishing system accuracy as a function of user location, satellite orbit parameters; and technology demonstrations, e.g., signal structure (coding and modulation), transmitters, receivers, and antennas.

One of the goals of the program will be to verify experimentally the relative contributions of system errors inherent in each advanced system being considered. This determination and verification will ensure the optimization of subsequent navigation systems prior to full operational deployment. The concurrent development of detailed satellite user link error models can be established to make use of measured and calculated parameters in order to compute and predict system performance in various anticipated environments.

The satellite navigation techniques experiment will provide a means of varying many of the parameters that affect the accuracy and costs of a navigation system, thus providing a means for system optimization. It will provide a demonstration vehicle for reasonably faithful simulation of operational geometry and parameter variation at substantial savings in time and money in comparison with the use of dedicated satellites. The engineering data provided will furnish meaningful input information for system decisions.

2. Background and Current Status

The determination of position and velocity of space vehicles by means of radio location techniques and extensive ground-based computer smoothing has been successfully and extensively employed in the guidance of ballistic missiles and in control of both automated and manned spacecraft. The basic limitations in the achievable accuracy have proven to be the result of our uncertainty about the shape of the geoid, and the tie-ins of geodetic datum reference points, such as found in Europe and North America. The amount of smoothing required and the time required to obtain a fix are limited primarily by the ionospheric and tropospheric propagation errors in a single measurement, which in turn depend on the frequency used. Errors due to the ionosphere decrease as a function of f^{-2} at very high frequencies and above, and thus may be reduced to an acceptable degree by the use of higher frequencies. Propagation errors due to the troposphere are essentially independent of frequency in the bands of interest and become the dominant source of error at C-band frequencies and above.

Although the desired accuracy of a single fix suggests the use of high frequencies, the requirement to achieve better than a minimum signal-to-noise ratio invokes a minimum requirement on transmitter ERP and receiving-antenna cross-section. Since the former is essentially limited by spacecraft technology and the latter implies receiving-antenna directivity at the higher frequencies, a compromise is required between the achievable system accuracy and receiving system complexity. The use of satellite techniques for navigation of terrestrial transportation vehicles (aircraft, ships, and other mobile units) seems to be a relatively simple and straightforward inversion of the system concepts and techniques already proven in space vehicle radio guidance.

The navigation requirements of high-velocity vehicles such as Mach 2 (and higher) aircraft are more stringent than those for slower moving objects since position and velocity updates must be available in near-real-time, i. e., within a time period proportional to d/v where d represents the required position accuracy and v is the vehicle velocity. Consequently, the minutes or hours of data smoothing to achieve the required accuracy by normal means are not available, and more advanced techniques of achieving near realtime position and velocity information must be considered.

The accuracy of navigation systems is constrained by a number of error sources which are well understood theoretically. The adequacy of this theoretical understanding is currently undergoing assessment in connection with such programs as Defense Navigation Satellite (DNS).

Special techniques, such as postdetection filtering (Kalman filter), may be used to improve the accuracy. Verification of theoretical analysis by experimental measurements is also needed before any meaningful development of theory can be made. System and data processing models for each technique are required. Significant work is being pursued on classified programs.

3. Description of Research

A comprehensive program, which includes simulation of system concepts such as ranging through the use of direct sequence codes or side-tone modulation; creation of, and testing with, the necessary ground environment (ground stations and user terminals); and development and demonstration of new technology, is required to expedite the development of components and to provide the engineering data upon which decisions to commit to a particular system development may be based. The economics of a practical navigation system require that all potential applications be considered, and particularly that the needs of the small user terminal be reflected in the final system decision.

Parameters to be examined include the following:

A. Determining the accuracy of a single observation of range, range difference, and velocity.

B. Determining the accuracy of modulation techniques and resultant hardware implications.

C. Incorporating a mechanization of matched filters and other means of reducing user-terminal costs

D. Employing adaptive modulation techniques to retain an inherent accuracy of the navigation system and reduce operational complexity and signal processing requirements.

E. Obtaining propagation error statistics on various choices of systems and system parameters.

For a practical test program, it may not be possible to fully simulate all aspects of system geometry; consequently, emphasis should be placed on system modeling and providing statistical inputs to the error models.

Applicable areas in which a body of theoretical knowledge exists, and in which data will be taken, include tropospheric propagation, ionospheric propagation particularly with regard to resulting time delay variations during signal transmissions, multipath and its effect on navigation errors, search and acquisition, detection theory, theory of matched filters, and modulation theory. Relative signal levels will depend primarily upon the detection technique and must be adjusted to meet the requirements of the system being simulated. Variations of 30 db in signal level are anticipated, with system thresholds of about -90 dbm and lower.

4. Impact on Spacecraft

Through combinations of reconfigurable space stations, subsatellites, and synchronous satellites (e.g., ATS), various candidate satellite navigation system configurations for the post-1980 era can be simulated and accuracy evaluated in the presence of multipath and other propagation effects. Man's in-orbit participation in the actual tests may be minimal, since the largest share of data processing or recording could be done at user terminals. But experimenter participation will usefully involve configuration of space hardware for the tests, turning on and tuning of equipment, and occasional equipment monitoring for satisfactory operation. Equipment operation could be automated, and the experiments themselves performed by automated subsatellites. The desirability of varying many of the parameters during the measurements, however, suggests the performance of the experiments in conjunction with a manned space laboratory.

5. Required Supporting Technology Development

Since this research cluster will make use of existing technology and the operational results obtained from ongoing programs, such as the COMSAT CORP AeroSat, NASA/ESRO North Atlantic ATC, and Defense Department's Transit and 621B programs, no new supporting research or technology is envisioned.

6. References

1. Navigation/Traffic Control Satellite Mission Study. Vol. I-III, CR-68166, CR-86167, CR-86168. TRW Final Report, NASA Contract NAS12-595, June 1969.

2. D.D. Otten. A Satellite System for Radio Navigation. AIAA Paper 68-1063, October 1968.

3. TRW Final Report Study and Analysis of a Navigation/ Traffic Control Technique Employing Satellites. TRW Final Report No. 08710-6012-R000, NASA Contract No. 12-539.

4. D.D. Otten. Satellites for Domestic Air Traffic Control. AIAA Paper 70-488, April 8, 1970.

5. P.I. Klein. Extension of Aeronautical Communications Satellites to Aircraft Position Determination (Surveillance) with Narrowband Channels. AIAA Paper 70-490, April 8, 1970.

6. R. Wachsman. Study of a Multipath Rejection Technique Applied to Aircraft Navigation by Satellite. ADCOM Final Technical Report of NASA Electronics Research Center, Contract NAS12-576, March 15, 1969.

7. K.L. Jordan. Measurement of Multipath Effects in a Satellite-Aircraft UHF Link. Proceedings of the IEEE Letters, 55, June 1967, pp. 1117-1118.

Critical Issues Addressed by Research Cluster

5-NS-1

SATELLITE NAVIGATION TECHNIQUES FOR TERRESTRIAL USERS

5.2.1.1.1
What are the effects of the ground system configuration, and the relay-satellite configuration, on the system accuracy?

5.2.2.1.1
What are the error probabilities of the low-orbit satellites, and how does this affect the overall system accuracy for one or more satellites?

5.2.2.1.2
How does the received noise power affect the accuracy of the range difference measurement?

5.2.2 1.3
Can the measurements provide the same accuracy as the error analyses indicate as feasible?

5.2.2.1.4
What is the accuracy which can be achieved by this technique, compared to other passive system techniques?

5.2.2.1.7
What are the system requirements, such as frequency, bandwidth, transmitter power, etc., for implementation of this technique and satisfaction of the accuracy requirements?

5.2.2.1.8
How does the accuracy of this system compare to that of other active systems employing spherical navigation techniques, and what are the cost penalties of the additional satellites?

5.2.2.1.10
What are the instrumentation requirements of the satellite and of the ground stations?

Table 1 /

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-NS-1 -1	Deploy antennas, electronic subassemblies, and establish configuration of sub-satellites.		3			21-A and 17-A	Initial	120-300	1-2			
-2	Deploy sub-satellites		4			21-A and 17-B	Initial	60-300	1-2			
-3	Turn on experiment equipment and perform equipment calibration		5			17-A	Initial	120-720	1-2			
-4	Monitor nominal operation of onboard supporting equipment		2			21-A	Intermittant	15-60	1			
-5	Monitor operation of experiment equipment.		5			17-A	Continuous	15 per data run	1			
-6	Control sub-satellites as required.		5			21-A	As Req.	30 per sub-sat.	1			
-7	Observe and record meteorological conditions in vicinity of user.		7			21-A	When in range	10-20 per location	1			
-8	Monitor and control the quality of transmitted signal, antenna orientation and quality of communications link.		5			17-A	Continuous	10-20	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—NAVIGATION
5-NS-2
Laser Ranging

1. Research Objectives

The objectives of this research cluster are to:

1. Evaluate the utility of onboard laser-ranging techniques for measuring range, line-of-sight angles, and closing rate between two spacecraft.

2. Evaluate the utility of onboard laser-ranging techniques for measurement of spacecraft altitude.

3. Define and characterize problems associated with the use of a laser ranger in the space environment and determine optimal engineering parameters under various modes of operation.

Experiments will be carried out, employing both cooperative and noncooperative targets. Use of laser ranging and tracking are of great interest for solving problems involving rendezvous and docking of one spacecraft to another, positioning and station-keeping of an unmanned satellite relative to a manned space station, and as an altimeter for maintenance of spacecraft altitude and possible geodetic measurement applications.

2. Background and Current Status

Unlike microwave radars, optical systems for a laser-ranging device may be constructed to maintain a very high degree of isolation between the transmitter and the receiver; allowing either continuous-wave or pulsed operation and further allowing measurement capability to essentially zero range. Short pulses available from such devices, coupled with the extremely narrow beamwidths that may be obtained from small physical apertures result in extremely good accuracy and resolution in both range and angle.

In the atmosphere, on the other hand, absorption and scattering of the laser beam are excessively high compared with the microwave spectrum, resulting in a very limited maximum range despite the high-energy density in the beam at the transmitter. Further, because of the very narrow beams associated with these devices, seach time and total search power for target acquisition may become excessive if the required search volume is of any great size. In applications where the location of the target can be estimated with reasonable accuracy (from known ephemeris, or through initial acquisition by a less-precise broader-beam sensor) laser-ranging techniques can be used to give precise characterization of the target position and rate. Thus, in applications, such as remote satellite station-keeping from a space station, or rendezvous and docking of a satellite to a space station, laser ranging techniques appear ideally suited.

Section of the operating wavelength for space-to-space operation of a laser ranger will depend on the detector's sensitivity; the efficiency of, and the power output available from, lasers at various wavelengths; and the spectrum of the background noise against which the system will operate. Background noise will vary greatly with the operating look angle at any particular moment. If the look angle is below the limb of the earth's atmosphere, background noise will be a function of two components: stellar noise reflected from the earth, and it atmosphere and radiation generated by the earth and its environment. If the look angle is above the limb of the earth, only stellar noise has to be contended with. This component of noise, however, will vary widely with look angle. If the noise spectrum is known, wavelength tradeoffs between detectors-transmitters and noise spectrum may be made in the laboratory to yield an optimal operating wavelength for space-to-space operation. Consequently, measurements in space at various wavelengths need not be a subject of this experiment.

A laser rendezvous and docking radar system with a maximum slant range of 120 km (75 miles) has been developed by ITT under contract to MSFC. This system is being considered for Space Shuttle and Space Base operations. The system employs a pulsed Gallium Arsenide diode laser beacon with a 10° search cone for initial acquisition. After alignment of the target vehicle, a corner reflector range returns some of the transmitted signal for measurement of angles, range and range rate. Both short-range and long-range tests have been conducted on an early prototype of the ITT system. Short range tests were made on the docking simulator at Martin Marietta Co. in Denver, Colorado. All docking runs (about 200) were successful, and the results showed (at point of docking) rms errors of < 0.1-meter range; a 1.6 cm/sec range rate; and lateral and vertical positioning errors of approximately 0.3 inches. Long-range tests were carried out between a helicopter and the University of California Research Station on the top of White Mountain. These tests were chosen to get above a large portion of the atmosphere, and successful acquisition and tracking were carried out against a sunlit cloud background. Adjusting the maximum range measured in these tests to space conditions yielded a maximum free space range of 95 miles. The target (helicopter) was a cooperative target with reflectance augmentation in the form of a 6-inch corner cube reflector. Analysis, however, has shown the maximum range of the system on an unaugmented target to be only about 1 mile. Thus, most space-to-space experiments in this cluster should utilize cooperative targets.

The use of a laser system as a spacecraft altimeter, either to obtain geodetic measurements or as standard instrumentation in the operation of a space station or other manned or unmanned space operation, the wavelength of operation must be picked to minimize atmospheric effects. Even then, the system would be nonoperational over areas of the Earth's surface that were shrouded from view by clouds or rain.

3. Description of Research

The experiment cluster consists of two separate and largely independent tasks laser radar operation between two space vehicles, and laser radar operation as a space-to-earth surface altimeter. Because of the differences in output energy required and the need to carefully select the operating wavelength of the altimeter to correspond to one of the windows in the Earth's atmosphere, two separate sets of transmitter and receiver equipment will be required.

In the space-to-space task, radar performance will be evaluated against a cooperative target (augmented with passive corner reflectors) at various ranges out to 300 nmi. Tests should be scheduled and carried out to include various background illumination conditions to be able to evaluate problems of target acquisition and tracking under a wide variety of noise conditions. In later phases of the testing, range and acquisition performance against noncooperative targets should be evaluated.

The purpose of the space-to-space task is to evaluate, under various signal-to-noise conditions, the problems associated with:

1. Initial target acquisition and lock-on.

2. Probability of detection.

3. Measurement accuracy.

4. False-alarm rate.

To evaluate target acquisition and lock-on, tests should be run (as a function of range), utilizing brute-force search and find techniques, diminished search volume techniques based on a priori knowledge of target location (known relative ephemeris of target relative to space station), volumetric spot lighting techniques, techniques associated with a broad-beam laser beacon mounted on the target, and acquisition assistance from a secondary tracking system having less special resolution.

To evaluate probability of detection, records should be made of measurement accuracy and false alarm, and measurement data of range and angle as well as range and angle rates; and these should be compared with simultaneous measurements of the same information taken with a second system of known accuracy.

The standard for range and range-rate accuracy calculations will probably be the spacecraft-to-satellite telemetry, tracking and control loop, the accuracy and performance of which have been well documented and qualified. One possible means of obtaining angle-comparison data would be to mount a high-intensity light source on the target and track this source by means of a star tracker with a narrow field of view. Care must be taken, however, to filter out the radiation in the spectral band of the laser radar to avoid creating confusion and bias in the tests. With a field of view of 1 degree for the star tracker, an accuracy of 1 arc second or less may be expected, depending on the intensity of the source being tracked.

In the tests against a noncooperative target, surface color and roughness characteristics may be an important parameter; however, the effects of this parameter may yield to laboratory testing and need not be tested in space.

As previously stated in the altimetry applications, the choice of laser wavelength is more critical here than in the space target case. This is because of the absorption and scattering properties of the Earth's atmosphere as well as the reflectivity of terrestrial features.

The purpose of this task will be to evaluate:

1. Accuracy and reliability of altimetry data obtained from a space-borne laser altimeter.

2. Use of the return signal signature to determine surface roughness and slope in the "foot print" of the altimeter on the Earth's surface.

3. Measurement of the effective thickness of the atmosphere in the laser wavelength spectrum.

4. Effect of cloud cover, weather patterns, climatic conditions, and geography on the performance of the altimeter.

To evaluate these properties, simultaneous altitude measurements with a high-quality microwave altimeter should be available. Visual or photographic observations of such parameters as cloud cover should also be made, and ground-truth data from actual land-survey measurements at known, selected locations should be made available for correlation with returned signal signature analysis.

4. Impact on Spacecraft

This experiment has no real-time data transmission requirement. The results would be recorded and transmitted at low rates when link capacity allowed.

The potential eye-damage interface posed by this experiment requires additional evaluation, especially for the space target situation. Protective glasses (narrow-band rejection filters) should be furnished to all crew members including members engaged in extravehicular activities who might be in positions where the beam could be observed directly or by reflection.

The generation of electromagnetic interference (EMI) by the laser modulator requires attention as a part of the general EMI problem.

Consideration of the optical elements of the laser radar system includes reliability under possibly large peak powers in the space environment, and the tradeoff concerned with placement of the transmitter and receiver front ends inside or outside the spacecraft. The thermal control and solar radiation shielding are additional inputs to this tradeoff.

The attitude control required will depend on the autotrack capability of the laser radar. This in turn depends on the signal-to-noise ratio, and so will depend on the system parameters and the tracker-to-target range. Attitude control for the altimeter experiments is less critical, but it does depend on the angular scattering response of the illuminated area (Lambertian, or highly directional).

The role of the space vehicle crew in these experiments, other than performing necessary maintenance and reconfiguration modifications will be that of monitoring experiment progress, obtaining data from other sensors for correlation of experimental results, and performing data-processing tasks.

For a laser radar system of the type under development by ITT, total weight will be about 30 pounds, and power consumption will be 25 w while operating. The equipment will be contained in two packages: the sensor package which will have a volume of approximately 0.60 cu ft with the longest dimension being 18 in; and an associated electronics package of approximately 0.7 cu ft, measuring 8 by 12 by 12 in.

Since the altimeter system will be of considerably higher power, it can be expected to occupy a volume of about 12 cu ft, weigh about 350 lb, and require an operating power of approximately 600 w.

5. Required Supporting Technology Development

Development of hardware required for this experiment cluster is currently well in hand, and necessary devices should be available in the time scale of the experiment. To optimize performance of a space-to-space laser radar, background noise spectral measurements over the range from 0.4 to 15.0 μ should be obtained. Such measurements should be made from space and characterize the spectral noise over the entire celestial sphere as well as the scattered and radiated noise from earth. Measurements may be made passively, using spectral radiometric devices. Information from these tests would be valuable in selecting an operating wavelength yielding a maximum signal-to-noise ratio in system operation. Such information would also be of value in design and performance evaluation of any type of sensor operating in this wavelength spectrum.

6. References

1. R.H. Dishington, W.R. Kook, and R.E. Brooks. Performance of RF and Laser Radar Systems. TRW Space Technology Laboratories Report 92002-137, November 11, 1963.

2. D.F. Nelson. The Modulation of Laser Light. Scientific American, Vol. 218, No. 6, June 1963.

3. G.A. Cato, L.W. Carrier, and K.J. von Essen. Laser Systems Study, Part III: Effect of Clouds. Report 4440-Final III, Electro-Optical Systems, Inc., December 14, 1965.

4. S.D. Kindorf and W.A. Specht. Relative Applicability of Radar and Laser Trackers for the AUTEC Andros Range Instrumentation. TRW Systems Study Report, October 11, 1968.

5. T.J. Gilmartin. 10.6-Micron Laser Radar Propagation Experiments. MIT Lincoln Laboratory, Lexington, Massachusetts.

6. H.A. Bostich and L.J. Sullivan. High-Power CO_2 Laser Radar System. Proceedings of the Fourth DOD Conference on Laser Technology, June 1970.

7. R.E. Johnston and P.F. Weiss. Laser Tracking System with Automatic Reacquisition Capabilities. Sylvania E Electronics Product, Inc., September 20, 1967.

8. A.A. Galvin. Lincoln Laboratory Laser Radar Program Reports.

9. M.I. Skolnik. Introduction to Radar Systems. McGraw-Hill Book Company, Inc., New York, 1962.

Critical Issues Addressed by Research Cluster

5-NS-2

LASER RANGING

5.2.1.1.4

What are the instrumentation requirements for the space vehicles for the different navigation systems?

RESEARCH CLUSTER NO. 5-NS-2

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-NS-2 -1	Set up laser experiment equipment to be compatible with radar test targets.		3			17-A	Initial	60-120	1-2			
-2	Monitor shuttle craft to determine separation of experiment module.		5			21-B	When available	60	1-2			
-3	Initiate laser equipment operation with experiment module carrying radar evaluation targets.		5			17-A		60-120	1-2			
-4	Monitor range, relative velocity, and angle tracking data.		5			17-B	Continuous	60-120	1			
-5	Make visual observations and photograph the experiment module.		7			21-A	When in range	30-60	1			
-6	Record output data of laser ranging system.		8			17-B	Continuous during test	60-120	1			
-7	Modify operating wavelengths and select alternate targets		4			17-A			?			
-8	Assess data outputs of experiment in progress using backup microwave radar.		6			17-A	Concurrent with test	60-120	1			-6

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

DO NOT REPRODUCE

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-NS-3
AUTONOMOUS NAVIGATION SYSTEMS FOR SPACE

RESEARCH CLUSTER SYNOPSIS–NAVIGATION
5-NS-3
Autonomous Navigation Systems for Space

1. Research Objectives

The principal research objectives of this research cluster are the performance evaluation and developmental studies of space navigation devices and techniques. Included in the research are navigation systems for in-orbit navigation for Earth and planetary orbiters, translunar and planetary navigation, and landing navigation for lunar or planetary missions.

The orbital environment of the space vehicle provides the research potential for these systems although, of course, only the near-Earth orbital trajectories are actually duplicated. The navigation system components that will be evaluated can be broadly broken down as follows:

1. Reference sensor systems.
   - A. Star trackers.
   - B. Inertial measurement systems.
2. Relative sensor systems.
   - A. Planetary RV sensors.
   - B. IR Sensors.
   - C. Optical landmark trackers.
3. Computer hardware and software.
   - A. Computer capacity and speed.
   - B. Program capability.
4. Man-computer interface.
   - A. Human role in inputting data and extracting data from the system.

This list of examples is not exhaustive. The research objectives, however, will be similar for any system component developed under these headings. Since software and man-machine interfaces are more amenable to Earth-based analysis, the focus of the research objectives in the spacecraft should be the performance assessment of the sensors. The capability of the navigation sensors to perform the mission can be predicted only when the sensor error models have been adequately defined. The research objectives, then, are to test the sensors under a variety of space-borne conditions so that the system error characteristics can be predicted for any combination of conditions likely to occur in operational use, even if such a combination does not or cannot occur in a space station environment. The experiments will typically attempt to relate sensor accuracy profiles to changing environmental conditions; for example, TV navigation sensor sensitivity to direct sunlight would be tested versus light level, enabling the analyst to construct this portion of the error model, which then would be used to predict sensor accuracy in the presence of direct sunlight of the magnitude anticpated on any mission. The development of a definitive error model for the sensors then permits a complete error analysis for any mission, provided the environmental conditions that drive the error model can be predicted. In many cases, partial error modeling can be accomplished in ground-based space simulations; the detailed performance assessments required for precision navigation systems, however, will require verification in an actual space environment.

2. Background and Current Status

Gemini and Apollo flights have demonstrated that faily simple, optically aided space navigation is feasible. The sensors involved, however, would be inadequate for long-duration planetary missions, or for precise planetary reentry and landing guidance without the radio-tracking support used on the Apollo mission. The primary experimental background in the autonomous navigation sensor performance has come from the TV experiments on the Mariner (Mars) flights, in which TV data were used to improve navigation estimates in the vicinity of the planets. TV navigation in conjunction with radio tracking is expected to be a key element in the performance of a grand tour-spacecraft. Clearly, the data on the performance of such sensors in various mission modes are very limited, and performance (or error) model development remains a key item in the research objectives. In summary, then, the techniques for utilizing onboard data are relatively well understood, and computer capability is not a limiting factor. The current status of sensor performance prediction in interplanetary and planetary orbiting and landing missions, however, is less advanced, being based on a small number of manned lunar unmanned planetary missions.

3. Description of Research

The nature of the research will be the testing and evaluation of a variety of sensors such as star trackers and sun and planet sensors, intended for autonomous navigation systems. By using the spacecraft's redundant navigation devices and ground tracking as well, a precise location and attitude reference standard is available. The accuracy of navigation sensor performance in angle and ranging (if applicable) is measured under a variety of conditions simulating (as far as possible) the operational environmental conditions. The variation in conditions should be those predicted to have the most severe impact on the sensor's accuracy, such as lighting, thermal state, landmark contrast, and atmospheric parameters). Methodical selection of the parameters of the test will, for each sensor, result in an error model sufficiently detailed to provide the basis for navigation system performance prediction.

4. Impact on Spacecraft

Since, in the final analysis, the navigation systems are intended for long-duration space missions, special attention must be paid to size, weight, and power consumption. None of the proposed navigation experiments, therefore, should make heavy demands on the spacecraft in these areas. The range of parameters over which the sensors must be tested, however, will require considerable freedom to direct the sensors in various directions. This requirement may call for special geometry of the sensors in the spacecraft, with consequent stabilization requirements for some of the experiments. If the viewing freedom necessary for the sensor experiment requires remote placement, accessibility by the crew will still be necessary for periodic maintenance or replacement. The inherent capability of the navigation system to operate autonomously, at least so far as the sensors are concerned, will considerably reduce the need for crew interfaces on the spacecraft itself. However, crew reports on system performance, and their capability to alter the test structure are valuable additions to the test program. The capability of the spacecraft to carry a wide variety of potential systems also means that system intercomparisons under the same environmental conditions can be made, a feature significantly enhancing the overall test design.

5. Required Supporting Technology Development

The navigation system components, particularly sensors, must be subjected to thorough ground tests before they are used on a spacecraft to predict performance. These ground tests, besides the obvious space qualification requirements, will identify the critical accuracy-sensitive error model parameters so that the proper spacecraft tests can be designed for specific error-model term resolution. Since optical navigation sensors, such as TV and star and planet trackers are identified as probably being key elements in future systems, supporting research will be required in ground-based space simulation facilities to identify the major factors in sensor total error. In near-planet operation (for orbiting, flyby, or landing), landmark tracking is known to be an effective navigation technique. Supporting research in pattern recognition and onboard computer enhancement for landmark identification will therefore be required to make full use of this technique in autonomous navigation.

6. References

1. J.E. Ball and T.C. Duxbury. Navigating the Grand Tours. Aeronautics and Astronautics, Vol. 8, No. 9, September 1970.

2. T.C. Duxbury. A Spacecraft-Based Navigation Instrument for Orbiter Planet Missions. Journal of Spacecraft and Rockets, Vol. 7, No. 8, August 1970.

3. J.E. Potter and W.E. VanderVelde. Optimum Mixing of Gryoscope and Start Tracker Data. Journal of Spacecraft and Rockets, Vol. 5, No. 5, May 1968.

4. N.F. Toda, et al. Region of Kalman Filter Convergence for Several Autonomous Navigation Modes. AIAA Journal, Vol. 7, No. 4, April 1967.

5. M.I. Smokler and P.M. Salomon. Photometric Calibration of the Surveyor Television System. Journal of Spacecraft and Rockets, Vol. 6, No. 11, November 1969.

6. A.E. Barth. Autonomous Space Navigation (Paper), 1970 Space Meeting, Institute of Navigation.

7. D.C. Fraser. Onboard Navigation Instrument Requirements for Orbiter-Planet Flyby Mission. 1970 Space Meeting, Institute of Navigation.

Critical Issues Addressed by Research Cluster

5-NS-3

AUTONOMOUS NAVIGATION SYSTEMS FOR SPACE

5.2.1 2.3
Is it feasible to mechanize this technique, and what are the cost and weight estimates?

5.2.1.2.4
Is it feasible to apply this technique under all conditions, or are there any constraints?

5.2.1.2.5
What are the mechanization requirements for the handover, and what additional instrumentation has to be tested?

Table 1
CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
5-NS-3 -1	Install and deploy navigation sensors.		3			21-B	Initial	120-240	1-2			
-2	Select appropriate computer programs and insert. Operate pointing and tracking telescope.		3			16-A	For each test		1			
-3	Initiate navigation system operation and make observations as appropriate.		5			16-A	2 drums	60-120 per data run	1			
-4	Monitor computer operation and sensor outputs.		5			16-A	Continuous during test	--	1			
-5	Make visual observations as applicable to sensors.		7			16-A	Continuous	15-30 per instrument	1			
-6	Monitor onboard navigation data and compare with ground-tracking-site data.		5			16-A	Continuous	60-20 per data run	1			
-7	Analyze and compare position information obtained from alternate on-board sensors.		6			16-A		As req.	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—NAVIGATION
5-NS-4
Surveillance Systems

1. Research Objectives

The objectives of the surveillance systems research cluster are to:

1. Demonstrate the utility of Earth-orbital satellites in extending the regions of controlled air space to areas where ground surveillance is either impossible or highly problematical.

2. Aid in the definition of an optimal system of air traffic control having global coverage.

The primary use of a satellite in air traffic control systems of the future will be as surveillance and relay links, interrogating inflight aircraft, collecting aircraft beacon information on position and velocity, and relaying this information to ground-receiving and data-processing terminals. When data processing centers on the ground determine the necessity of altering the flight path of an interrogated aircraft to avoid a collision or for other reasons, the satellite will also be used to relay such instructions from the ground terminals to the aircraft. Little or no data processing by the satellite relay is envisioned unless such processing could materially reduce the loading of the ground station without destroying the effectivenss of the overall system.

Operational satellite-borne air-traffic control systems of the future will undoubtedly utilize either satellites in Earth synchronous orbit, a constellation of nonsynchronous satellites of sufficient number to give global coverage or a combination of synchronous and nonsynchronous satellites. These satellites will be completely automated. The purpose of this research cluster is to contribute directly to NASA's stated objectives by facilitating the development of advanced space techniques which could be used to provide services to commercial and private aviation and in avoidance of collision between aircraft.

2. Background and Current Status

A surveillance system for aircraft traffic control must be capable of detecting all aircraft within its sphere of influence and providing total kinematic data in terms of aircraft position and velocity. In the aircraft traffic-control center, these data would be analyzed to predict the tracks for each aircraft in the sector; and compute required adjustments of the flight paths of aircraft on collision courses, taking into account the possible hazard to other aircraft in the sector. The surveillance system must further be capable of relaying required flight-path adjustments back to all endangered aircraft. Such a total system must also have accurate information on the maneuver capabilities of the involved aircraft types and on the response time of the pilots to a maneuver command to be totally effective in analyzing and preventing midair collisions.

ATC systems in current use, or under study for future use, utilizing ground-based surveillance radars against active beacons within the aircraft, are plagued by many problems that would be greatly alleviated or eliminated altogether through the use of space-based surveillance.

For current systems, in areas of high-traffic density, these problems include:

1. Low "round reliability." (Round reliability is the probability that a given interrogation will elicit a reply from a particular transponder.)

2. Reflections from nearby vertical surfaces, which result in false azimuthal information.

3. Inadvertant shielding of the transponder antenna beam as the result of aircraft maneuvers (particularly at low altitudes).

4. Synchronous garble resulting from overlapping of replies from two aircraft in close proximity.

5. "Fruit" or asynchronous replies triggered by signals other than the interrogating station.

6. Shielding of the interrogator due to land obstructions or other objects, resulting in blind spots at certain azimuths from the interrogating station.

7. Vertical lobing patterns due to the multipath phenomenon.

8. Side-lobe interrogation of transponder-equipped aircraft in close proximity to the beacon ground station.

Most beacons currently in the use or proposed are built to have a dead-time after reply equal to or greater than the duration of the reply code. In areas where the beacon may be subject to interrogation from many sources, round reliability from any particular interrogator may be quite low since the probability of interrogation during transponder dead-time in such situations may become rather large. Further, asynchronous replies triggered by sources of radio-frequency interference associated with other equipment onboard the aircraft, or dead-time introduced to prevent side-lobe interrogation can all add to the problem of low round reliability.

Although the theory of radio location and random access is well in hand, the achievable location accuracies, as an example, have yet to be verified. Propagation tests of the 5-P series of experiments will provide data relevant to the surveillance tasks.

3. Description of Research

The experimental approach consists primarily of configuring the space laboratory with transponders at various assigned frequencies. Equipment requirements include appropriate antennas, diplexers, receivers, frequency translators, and transmitters capable of operating in either a continuous-wave mode or a wide-bandwith pulsed or modulation mode. Some of the equipment may well be hardware common to other experiments, thus reducing the cost, weight, and volume effects on the spacecraft. Since the spacecraft will employ low orbits, data storage for transmission when the craft is in range of a ground terminal will be required. Early phases of the development may include onboard data processing evaluation as a means of alleviating the requirements for onboard storage.

Appropriately located ground based transponders (in the area over which tests will occur) may be useful for the simulation of other satellites of the final net. Initial tests should be run with a single aircraft in order to establish best transmission frequency, accuracies of location and positioning of the aircraft, etc. Later testing could include multiple aircraft in relatively close proximity (10 to 100 miles apart) to each other. Ground truth data on aircraft position at time of interrogation will be required in order to analyze the accuracy and round reliability of the satellite collected data.

4. Impact on Spacecraft

Generally, these experiments will place only modest demands on the spacecraft system. Since it is envisioned that the equipment required (at least in part) may already be available aboard the spacecraft as part of the normal requirement or associated with other experiments (particularly those of the communications services), little penalty in overall weight, volume, or power requirements will accrue as the result of including this experiment cluster.

Astronaut participation in these tests consists primarily of configuring and setting up the equipment as required, monitoring equipment for nominal operation, calibrating the equipment, and possible some assistance in data processing in the early phases of the program. In later phases, data will be returned to ground-based centers for reduction and analysis.

5. Required Supporting Technology Development

Spacecraft to Earth station communications experiments included in other clusters will provide the necessary propagation information for final selection of frequency for a satellite-borne surveillance system. In performing such experiments, ray-bending effects due to refraction in the ionosphere must be carefully evaluated since these effects will contribute directly to the accuracy of thesurveillance system. Equipment technology is presently well in hand although present and future developments in integrated circuitry may well reduce the impact of added weight, volume, and power on the spacecraft.

6. References

1. W. L. Ashby. Future Demand for Air Traffic Services. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

2. J. Holt and G. R. Marner. Separation Theory in Air Traffic Control System Design. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

3. K. A. Shaw and A. A. Simolunas. System Capability of Air Traffic Control Radar Beacon System. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

4. S. M. Weinstein. Beacon Target Processing for Air Traffic Control. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

5. R. C. Renick. An Improved ATC Radar Beacon System. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

6. J. B. Woodford and R. L. Dutcher. A Satellite System to Support an Advanced Air Traffic Control Concept. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

7. R. W. Meier. North Atlantic Aeronautical Satellite System Development. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

Critical Issues Addressed by Research Cluster

5-NS-4

SURVEILLANCE SYSTEMS

5.1.1.4.4 Mobile Platform Location Techniques (2-KM Accuracy)

5.2.2.2.1
What techniques and signal designs are available to satisfy the multiple user requirements and aerial coverage of the system?

5.2.2.2.2
What are the projected system requirements in connection with the anticipated number of users and frequency of reporting, and what system designs will satisfy these requirements?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 5-NS-4	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-NS-4 -1	Deploy antennas		3			21-A & 17-B	Initial	10-30	1			
-2	Set up experiment test equipment and calibrate		3			17-A	Once per data run	120-300	1-2			
-3	Configure and deploy the subsatellites		3			21-A & 17-B	Once per mission	120-300	1-2			
-4	Initiate test equipment and monitor nominal performance		5			17-A	20 runs Continuous during test	60 per data run	1			
-5	Adjust equipment and correct malfunctions if they occur		6			17-A	As Req.	--	1			

†See Legend of Codes, next page. ‡X(or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

Do Not Reproduce

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER—5-NS-5
COLLISION AVOIDANCE SYSTEM TECHNIQUES

RESEARCH CLUSTER SYNOPSIS—NAVIGATION
5-NS-5
Collision Avoidance System Techniques

1. Research Objectives
The primary objective of this research is to demonstrate the utility of a satellite to provide time-reference signals for collision avoidance systems.

Present and future concepts for collision avoidance systems (CAS), as developed by the Air Transport Association, requires precise time synchronization of basic clock drives between all cooperating aircraft. Three methods of synchronization appear feasible:

1. Synchronization to the fastest aircraft clock within line of sight.

2. Ground synchronization.

3. Stable, accurate airborne clocks with a voting between systems within communications range to select the master.

Synchronization to a single satellite-borne clock would alleviate many of the difficulties associated with the methods listed. Further, a global coverage network of synchronous satellites could provide, in essence, a single time reference to all aircraft. Such a system could improve traffic flow over high-density transoceanic routes; and reduce over-ocean aircraft-separation standards, thus improving the efficiency of utilization of air space and demonstrating U.S. leadership in pioneering new space applications and services.

2. Background and Current Status
Several collision-avoidance systems that use time synchronization as a critical element have been developed. Most of these systems have been developed by the military services for use on military aircraft during formation flight. A midair collision of two experimental aircraft under development and test led to the development of the EROS I collision-avoidance system designed to prevent random encounter.

Maintenance of synchronization in areas of traffic density remain a major problem in these systems. Satellite-borne clocks could alleviate this condition by providing synchronization to a wider area from a single source. Utilization of such a system, however, requires evaluation and compensation for diurnal and seasonal variations in satellite-to-earth radio-frequency propagation resulting from changes in electron density and altitude of the various layers of the earth's ionosphere.

3. Description of Research

Initial experimentation will be carried out between the spacecraft and a ground terminal. A common time-synchronization signal will be transmitted from the satellite at four different frequencies, very high frequency, C-, L, and X-band. The receiving ground station will record and compare the demodulated clock signals from the three different transmission frequencies. To evaluate effectiveness over the entire Earth surface, various spacecraft orbit inclination angles (including polar or near polar orbits) will be required. For tests in locations inaccessible as ground-based terminals, aircraft may be used as the Earth station. Various modulation techniques will be employed to determine which is best suited for use in the final system, i.e. PCM, FM, etc.

4. Impact on Spacecraft

Onboard equipment required for this experiment will include necessary antennas, transmitters, and modulators, and a master stable clock from which time signals may be derived. The use of multipurpose equipment necessary for other experiment clusters or normal spacecraft operation can greatly reduce the impact of this experiment.

Primary use of astronauts stationed aboard the satellite would be in setting up and monitoring the experiment-required equipment, performing equipment modifications as required, and servicing and maintaining this equipment.

5. Required Supporting Technology Development

Current hardware development seems sufficient to support the needs of this research cluster. Results of space-to-ground radio propagation tests proposed for other clusters could greatly enhance the results of this research and the time required for defining a viable final system.

6. References

1. B. Alexander. Aircraft Density and Midair Collision. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

2. H.A. Steinberg. Collision and Missed Approach Risks in High-Capacity Airport Operations. Proceedings of the IEEE, Vol. 58, No. 3, March 1970.

3. M.R. Bates, et al. History of Time-Frequency Technology. IEEE Transactions of Aerospace and Electronic Systems, Vol. AES-4, No. 2, March 1968.

4. R.J. Jaycox. Collision-Avoidance System Synchronization. IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-4, No. 2, March 1968.

5. W.G. Shear. Elements of the ATA Collision Avoidance System. IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-4, No. 2, March 2, 1968.

Critical Issues Addressed by Research Cluster

5-NS-5

COLLISION AVOIDANCE SYSTEM TECHNIQUES

5.2.2.3.3
What is required to integrate a Central Processing System with individual beacon transmissions?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 5-NS-5	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-NS-5 -1	Erect or deploy antenna		3			21-B	Initial	60-300	1-2			
-2	Connect transmitter, turn on experiment apparatus and set clock timer for experiment turn-off.		5			17-A	Initial	60-300	1-2			
-3	Observe power output meters		5			17-A	Initial	5-10	1			
-4	Communicate with ground control as necessary		9			17-A	20 x mission As Req.	30 per trans-mission	1			
-5	Repair and/or maintain equipment as required		4			17-B	As Req.	--	1			
-6	Check waveforms for satisfactory operation		5			17-A	Every 6 Hrs	30-60 per data run	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

RESEARCH CLUSTER SYNOPSIS—NAVIGATION
5-NS-6
Search and Rescue Systems

1. Research Objectives

Detection and localization of an emergency location transmitter (ELT) by a satellite would greatly aid search and rescue operations. The objective of this research is to provide operational data relevant to a critical technical area, specifically the uplink from the ELT to the satellite. This will then permit realistic tradeoffs in determining an optimum system.

Major problems that should receive orbital verification include (1) determination of the best frequency for detection and localization, (2) determination of the optimum feasible location method (e. g., ranging, doppler shift, or angle measured from a satellite), and (3) determination of suitable modulation techniques. The research clusters under 5-P and 5-N will provide some of the required data. One consideration in modulation may be techniques that are compatible with matched filter-detection design and implementation.

The detection and modulation theories appear adequate for the task, but practical problems in implementation must be solved and measurement of performance under operational conditions is required.

2. Background and Current Status

Current search and rescue operations lack adequate capability in two areas:

1. The timely detection of a distress situation.

2. The timely localization of an emergency transmitter (ELT).

Although various search and rescue (SAR) systems using satellites have been conceived, none has currently progressed beyond the proposal stage. Emergency location transmitter concepts being supported by the FAA are primarily suited to aural detection by aircraft pilots and are not intended for satellite detection and location techniques. One preliminary study has shown that the existing (FAA) ELT requirements may result in a marginally adequate signal-to-noise ratio at the satellite. Also, the frequency stability specified for the ELT would limit the accuracy of position determination based on measurement of doppler frequency.

3. Description of Research

The research cluster activities consists of validating the operation of spacecraft components and simulation of an operational system. When spacecraft in low orbits are employed, a store and forward mode of operation may be required, if data are processed on the ground. Early phases of development may include onboard data processing and evaluation, although this will not be the final mode of operation.

4. Impact on Spacecraft

An operational search and rescue satellite system will probably use polar orbits, but is not necessary for completing this research cluster. The orbit altitude should be between 400 and 1000 nmi to provide propagation paths duplicating those of the systems under consideration. Lower orbits will improve S/N ratio but change the geometric relationships slightly, such as reducing the acquisition time of the ELT.

Astronaut operations will include deployment and calibration of equipment, reconfiguration for other tests, monitoring the performance of relay equipment, and observing the results of onboard processing. Data are returned to Earth for ultimate system evaluation.

5. Required Supporting Technology Development

A technology area which requires further investigation is accurate doppler frequency measurement at very low signal-to-noise (<6 db) ratios. Further study is also required of candidate systems, especially with regard to position location within the framework of existing (FAA) ELT concepts.

6. References

1. A Proposal for the Study of a Search and Rescue Satellite System. TRW Systems, May 12, 1969.

2. Useful Applications of Earth-Oriented Satellites: Navigation and Traffic Control. NASA-CR-101409, National Academy of Sciences. June 1969.

3. FAA Technical Standing Order TSO c-61a. (See also California Standards for Emergency Locator Transmitters, Title 4, Subchapter 5, of California Administrative Code.)

Critical Issues Addressed by Research Cluster

5-NS-6

SEARCH AND RESCUE SYSTEMS

5.2.2.5.1

What are the system characteristics which satisfy the angle determination requirements for low-power beacons, and how can these characteristics be implemented?

5.2.2.5.4

Can this function be integrated with the required traffic control communications, and what additional equipment is needed to provide this function?

Table 1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 5-NS-6

RESEARCH CLUSTER NO. 5-NS-6	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION †	TASK CONCURRENCY†
5-NS-6 -1	Deploy antennas and configure experiment test equipment.		3			21-A & 17-B	Initial	60-300	1-2			
-2	Perform calibration of experiment test equipment.		4			17-A	Initial	60-300	1-2			
-3	Initiate experiment operation		5			17-A	Initial	--	1			
-4	Monitor data output and control data processing.		8			17-A	Continuous	20 runs 60-120 per data run	1			
-5	Maintain communications with ground control as required.		9			17-A	Every 4 Hrs	30	1			
-6	Perform calibration of receiver as necessary.		4			17-A	As Req.	20 turns 60 per test	1-2			
-7	Modify data processor after coordination with principle investigator.		5			17-A	As Req.	60-120	1			

†See Legend of Codes, next page. ‡X (or other entry) indicates that time of crew members cannot be shared with any other task.

LEGEND OF CODES USED IN TABLE 1.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.